COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

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September 1952

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A Study in Reflections

Piacenza Station of the Societa Edison

Utilization of Low-Grade Coals

Engineering Economy in the Utility Industry

VU -the choice of Leaders in every Industry

Wherever steam is important for power, heating or process — you'll find C-E Vertical-Unit Boilers (Type VU) establishing new standards of reliable, efficient operation. In industry after industry, leading manufacturers are setting the pace with VU Units.

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Swift & Co., Inc.
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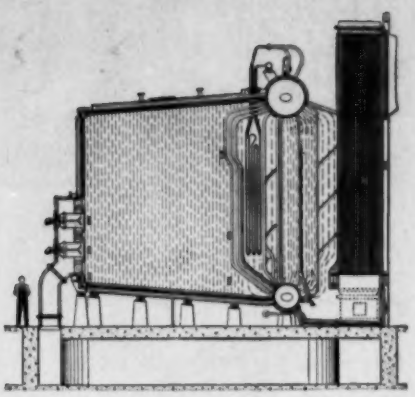
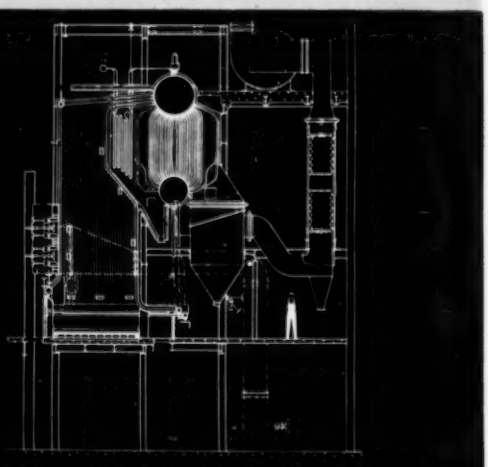
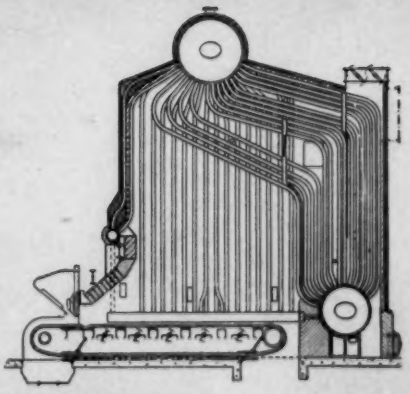


VU-50 Boiler — This unit is one of two duplicates installed in a brewery. They are fired with oil or gas. Capacity — 100,000 lb of steam per hr; operating pressure 550 psi; steam temperature 700 F.



VU-40 Boiler — This unit is installed in the plant of a food product company. It is fired by oil; arranged for future pulverized coal. Capacity — 60,000 lb of steam per hr; operating pressure — 250 psi; steam temp. 600 F.



VU-10 Boiler — This unit, one of three duplicates, is installed in a food processing plant. It is fired by a chain grate stoker. Capacity — 25,000 lb of steam per hr; operating pressure — 125 psi; no superheat.

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COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 24 **No. 3**

September 1952

Feature Articles

Piacenza Station of the Societa Edison ..... *by Dott. Ing. Franco Castelli* 36

Utilization of Low-Grade Coals for Power Generation *by Richard C. Corey and James W. Myers* 43

Modern Steam Plant at Villanova College 50

Engineering Economy in the Electric Utility Industry ..... *by K. M. Irwin* 53

Improved Utilization of Waste Heat ..... *by Ing. Dr. Richard Dolezal* 57

Editorials

Better Utilization of Engineers Advocated 35

When is "Big" Too Big? 35

Another Italian Power Station 35

Departments

Facts and Figures 49

Catalogs and Bulletins 65

Advertisers in This Issue 78

COMBUSTION publishes its annual index in the June issue and is indexed regularly by Engineering Index, Inc.

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Published monthly by COMBUSTION PUBLISHING COMPANY, INC., 200 Madison Ave., New York 16
A SUBSIDIARY OF COMBUSTION ENGINEERING-SUPERHEATER INC.

Joseph V. Santry, President; Charles McDonough, Vice-President; H. H. Berry, Secretary and Treasurer
COMBUSTION is sent gratis to engineers in the U. S. A. in charge of steam plants from 500 rated boiler horsepower up and to consulting engineers in this field. To others the subscription rate, including postage, is $3 in the United States, $3.50 in Canada and Latin America and $4 in other countries. Single copies: 30 cents.
Copyright 1952 by Combustion Publishing Company, Inc.
Publication Office, Easton, Pa. Issued the middle of the month of publication.
Acceptance under Section 34.64, P. L. & R., authorized by United States Post Office.

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Bryce E. Morrow Plant Comstock, Michigan....	2	F W	875	400,000
	1	F W	875	550,000
	1	F W	875	600,000
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	2	F W	875	550,000
	2	F W	875	600,000
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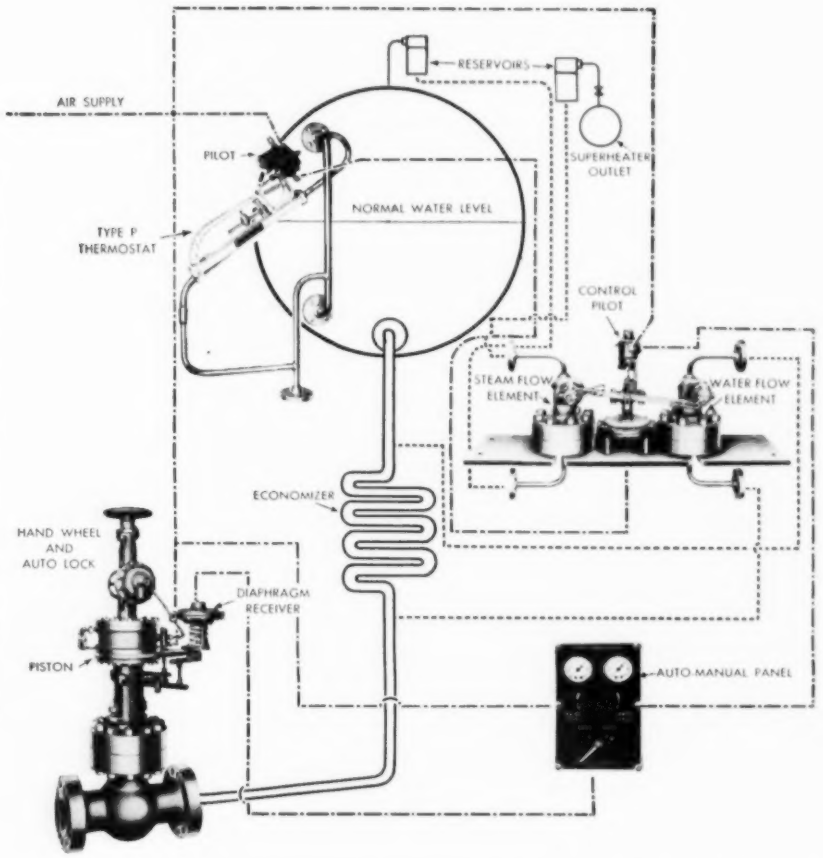
	1	B&W	1600	860,000



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Editorials

Better Utilization of Engineers Advocated

Speaking before the Cornell Society of Engineers at Chicago on September fifth, Dean S. C. Hollister of the Cornell College of Engineering predicted a profound change in practice of the engineering profession during the next quarter century. This, he explained, will be brought about largely because the need for engineers will increase more rapidly than the available supply, since technological processes are becoming more complex.

Noting that engineers are often employed in more or less subprofessional tasks, he proposed that engineering aids and technicians be trained to handle such work, thus leaving the professional engineer free to devote more time to the overall job of planning and direction. A parallel situation exists in the medical field where therapists, laboratory technicians and nurses are employed to extend the doctor's services.

Some educators contend that, because of the ever-increasing requirements of the profession, the number of high school graduates possessing the necessary inherent qualifications is limited. On the other hand, there should be much promising material available, both male and female, from which aids and technicians could be selected and trained. Not only would shorter periods of training be involved, but it is conceivable that many such individuals might prove more proficient in their restricted tasks than the engineer with his broader training.

The idea, of course, is not entirely new. It has long been carried out by a few of the larger companies as regards calculators, research workers, etc., but the practice has not become general.

As a corollary to such upgrading, Dean Hollister believes that engineers must be better trained, in which connection he said:

"As each engineer must extend himself over more territory through the aid of others, it will be essential that he be trained at a higher level in order to do such directive work more efficiently. Such a rearrangement of engineering services will result in an improvement whereby the social status of the engineer will increase his value to his employer, and this, in turn, will improve his economic status."

When is "Big" Too Big?

What is the ultimate economic and physical limitation on the size of the single boiler-turbine-generator unit? Is there any danger from the standpoint of electrical system stability and concentration of large blocs of power in "putting too many eggs in one basket"?

At the 1951 ASME Annual Meeting, Philip Sporn offered the following convincing explanation concerning the decision of the American Gas & Electric System to install 200,000-kw boiler-turbine-generator units at the Kanawha and Muskingum River plants:

"Thermal economies hitherto unattained are a basic inherent advantage realized by the units. . . . A heat rate of the order of 9000 Btu per kilowatt-hour, with fuel costing 16½¢ per million Btu, results in a unit fuel cost of less than 1.5 mills per kilowatt-hour. There are also other operating savings . . . found in the labor needed to run and maintain the larger units, and in material and supplies entering in the same operations. . . . Unit costs for both boiler and turbine are less than the unit costs of smaller machines because there are very few, if any, more component parts in a 200,000-kw unit than in a 100,000-kw unit. Piping is another striking example of the advantages which accrue from the use of the larger units. . ."

With characteristic foresight, Mr. Sporn also asserted in the same ASME paper: "If the trend in size, and the criteria for determining size of system units, are to be the same in the future as in the past, then units larger than 200,000 kw are indicated for installation in the relatively near future."

That "future" has already arrived, according to a news release from the Westinghouse Electric Corporation announcing the signing of a contract with the Tennessee Valley Authority for two 250,000-kw single-shaft, 3600-rpm, triple-exhaust turbine-generators. What reason is there to believe that this is the limit? And if not, at what point, if any, does the economic law of diminishing returns apply to boiler-turbine-generator unit capacity?

The history of engineering developments provides many examples which show that mere enthusiasm for size, however meritorious and practical from a physical standpoint, may seriously conflict with sound economics and rational industrial growth. For the reader who likes to speculate, we ask—in terms of boiler-turbine-generator units—when is "big" too big?

Another Italian Power Station

During the past year COMBUSTION has been privileged to publish descriptions of a number of new Continental European power stations in Italy, Holland and Belgium. Some of these were built with Marshall Plan aid, whereas others were privately financed. In a few cases American equipment predominates, while in others it is largely of European design and manufacture.

These are only a few of the large number of new plants recently completed or under construction abroad with the aim of meeting the greatly increased postwar power demands. A description of another such station, at Piacenza, Italy, appears in this issue, and we contemplate describing others in the near future.

In some of these installations the influence of American practice will be detected, but this is limited in many cases by local factors such as available European coals, load conditions and local economic considerations. Therefore, one should hesitate at making comparisons without knowing and carefully weighing all aspects of each case.

PIACENZA STATION of the Societa Edison

This 100,000-kw, 1450-psi, 1000-F reheat installation of two units is housed in the old plant building which has undergone extensive alterations to accomodate the new equipment. Natural gas or fuel oil are the primary fuels.

By Dott. Ing. FRANCO CASTELLI
Chief Engineer of Thermal Plants

ANOTHER important Italian central-station installation now nearing completion[1] is that of the Societa Edison at Piacenza, some 35 miles southeast of Milan which will tie in with an extensive transmission system in northern Italy. Here it was decided to remove the existing old equipment, but to utilize the reinforced concrete building to house a modern high-pressure plant of 100,000 kw initial capacity.

This involved alterations to the building and considerable rearrangement. Although use was made of the existing floors, their functions were revised. What was formerly the operating floor became a secondary platform level, and the top floor which formerly supported the boilers was utilized to carry the fans and stacks. Numerous stiffening members were added to resist vibration, and new roof supports at higher elevation replaced existing trusses.

In order to provide and support additional floors, a steel structure was erected within the existing building. New steel columns were placed in proximity to the existing concrete columns and tied at intervals to the latter to increase stability. In general, all new loads were supported up from the foundations by steel framing, except where an existing floor had sufficient strength to assume the loading of a new floor above.

Much of the major equipment is of American manufacture and the installation is laid out on the unit principle with each turbine-generator served by a single boiler having no cross-connections.

Boilers

There are two Combustion Engineering-Superheater high-pressure reheat boilers of the single-drum type complete with convection superheaters and reheaters, economizers, regenerative-type air heaters and fuel burners for use with either natural gas or "Bunker C" oil. Provision has been made for burning Sardinian coal in the future.

Each boiler is designed to produce 450,000 lb of steam

[1] For descriptions of the Genoa and Tavazanno plants see COMBUSTION of March and July 1952, respectively—EDITOR.

Turbine room as it appeared in June 1952

per hour at 1510 psig 1000 F at the superheater outlet. The reheat section is designed to raise the temperature of 410,000 lb of steam per hour from 750 F at 387 psig to 1000 F at 363 psig.

Superheat steam temperature is regulated by operation of a spray-type desuperheater with one desuperheater provided for the superheater section of each boiler.

Reheat steam temperature is regulated by means of automatic motor-operated, burner-tilting mechanism as a primary control and an automatic motor-operated proportioning valve, located in the spray type, desuperheater feedwater line as a means of secondary control.

Each boiler has an Elesco horizontal finned-tube economizer designed for counterflow, and containing 6950 sq ft of heating surface. The gas inlet and exit temperatures are 720 and 650 F. respectively, and the feedwater enters the boiler drum at 466 F.

Draft Fans

There are two 102,000-cfm forced-draft fans driven by two-speed motors for each boiler. For high ratings a 1450-rpm, 350-hp 3000-volt, 50-cycle winding is used, and for lower ratings a 970-rpm, 125-hp 3000-volt, 50-cycle motor winding is available. The air delivered from the forced-draft fans is forced through a preheater of the plate type which raises its temperature from 80 or 100 F to about 560 F before passing to the burners.

To prevent the deposit of moisture and possible plugging between the plates near the entrance of the air heater, a bypass arrangement is provided to divert some of the 560-F air to the intake of the forced-draft fans, thereby raising the inlet air temperature. The amount of air bypassed is controlled by a damper automatically adjusted to maintain an inlet temperature of 150 F.

Two 137,000-cfm induced-draft fans serve each boiler. These have two-speed motors. For high ratings a 970-rpm, 600-hp, 3000-volt, 50-cycle motor winding is used, and for lower ratings there is a 735-rpm, 350-hp, 3000-volt, 50-cycle motor winding.

Fuel Oil and Gas Systems

Each boiler has eight tangential Peabody wide-range mechanical-atomizing burners, located two per corner. They are vertically adjustable for steam temperature control.

"Bunker C" oil is stored in an existing underground storage tank with a capacity sufficient for 6½-days operation of two boilers at full load. Oil is transferred from the underground tank to two day tanks having a total capacity of 84,000 gal which provides an additional ten hours of storage capacity. These tanks contain steam heating units to maintain the oil at about 100 F. Three 85-gpm motor-driven Sier-Bath fuel-oil pumps, deliver oil at a pressure of about 660 psi to a group of heaters which raise the temperature to 220 F. The arrangement of piping is such that oil is delivered through a control station to the suction of the constant-differential pump at a pressure of 600 psi and a temperature of 220 F.

The constant-differential pump operates in a continuous piping loop to and from the oil burners at pressures ranging from 600 to 750 psi and maintains a constant-pressure drop across the oil-burner nozzles, providing efficient atomization of the oil at all loads within the operating range of the equipment.

Each boiler has sixteen tangential gas nozzles designed to operate at 0.5 to 2 psig; they are arranged four per corner. The natural gas is obtained from an 8-in. high-pressure main supplying gas at 5 to 55 atmospheres at about 40 F. The gas is passed through a fin-tube-type heater, raising the temperature to 100 F and a pressure-reducing and metering station, reducing the gas-supply pressure to 3.5 atmospheres. A gas-control station is provided with the 8-in. main-gas-control valve equipped with an adjustable minimum stop to prevent closing of this valve below a safe stable ignition point.

In addition to a calorimeter (BTU meter), provision has been made for recording gas temperature and pressure and measuring gas flow to each boiler, which at maximum load is expected to be 28,500 lb per hr.

The boilers have gas warming-up torches located one per corner and designed to produce approximately 90 million Btu each. The purpose of these gas warming-up torches is to permit a gradual warming up of the furnace while approaching actual operating temperatures and so avoid possible damage due to sudden temperature changes.

There are also four gas-pilot torches per boiler, one located in each corner of the furnace. There purpose is to light off the main burners while providing flame stabilization and a source of constant ignition in the furnace at low roads.

Television equipment is installed complete with cameras and receivers for observation in the control room of the boiler-drum, water-level gage glass and furnace flame, the Diamond Utiliscope having been specially adapted to view non-luminous gas flames.

Combustion Control

The combustion control system is designed to provide complete automatic control, with provisions for remote manual operation when burning either gas, or a combination of gas, oil or coal. Regardless, however, of what fuel or combination of fuels is burned the combustion control system is fundamentally designed to automatically hold constant the steam pressure, fuel-air ratio, and furnace draft at the values required for a particular load setting.

In addition, the system provides for remote manual regulation of forced- and induced-draft fan outlet dampers. Another design feature incorporated in the control system provides for the limiting of fuel consumption when operating with a single forced-draft fan and the maximum capacity of that fan has been reached, or when operating with two forced-draft fans and one fan is suddenly shut down

When burning natural gas as a combination with other fuels it is possible to set, by means of an adjustable fuel limiting device, the maximum rate of gas consumption and establish a fixed or base load on the boiler for this fuel. The variation above this base load would then be absorbed by either oil or coal depending upon what combination of fuels is used.

Control Air Compressors

A comprehensive automatic control system employing compressed air at 90 to 100 psi, has been installed. This employs a separate compressor. After leaving the compressor, the air is passed through drying towers before being fed to the control drives. That portion of the air

supply used for the operation of the controllers and control relays is passed through additional filters to insure perfect functioning of the pneumatic control system. As a reserve, the control air can be taken from the plant compressed air system, the connections being such that the cleaning and drying processes continue to function.

Turbine-Generators and Condensers

Two Westinghouse turbine-generators, each having a nominal rating of 50,000 kw at 80 per cent power factor, generate three-phase 50-cycle power at 13,800 volts. The maximum capability is 62,500 kw. Each turbine receives steam from one boiler at a throttle pressure of 1450 psig and a temperature 1000 F and exhaust to a 37,500-sq ft condenser at an absolute back-pressure of 1.25 in. Hg. The arrangement is such, that there are no cross-connections, and the two units are independent of each other.

Each unit consists of a two-cylinder, tandem-compound, condensing reheat turbine coupled to a hydrogen-cooled generator. The turbine contains high-, intermediate- and low-pressure elements. The high-pressure element is of the combination impulse-reaction type, the intermediate-pressure element is of the straight-reaction type and the low-pressure element a straight reaction double-flow machine with steam entering at the center of the blade path and flowing toward an exhaust opening at each end.

The turbine has six extraction nozzles from which superheated steam at various pressures is taken for the feedwater heaters. The major portion of the steam from the turbine, about 300,000 lb per hr, passes to the condenser at a pressure of $1^1/_4$ in. Hg and at a temperature of 86 F.

The condensers are of the horizontal, two-pass type with divided water boxes. Each represents a total cooling surface of approximately 37,500 sq ft, the average river water temperature is around 66 F. Division valves in the water boxes make it possible to maintain circulating water flow through the condenser with only one circulating pump in service.

Water is delivered from the Po River to the two condensers by four vertical circulating water pumps of 19,000 gpm. The hydraulic grade line from the circulating-water pump discharges to the outlet at the condensers is such that the system is aided by a 25.76 ft siphon at the condensers.

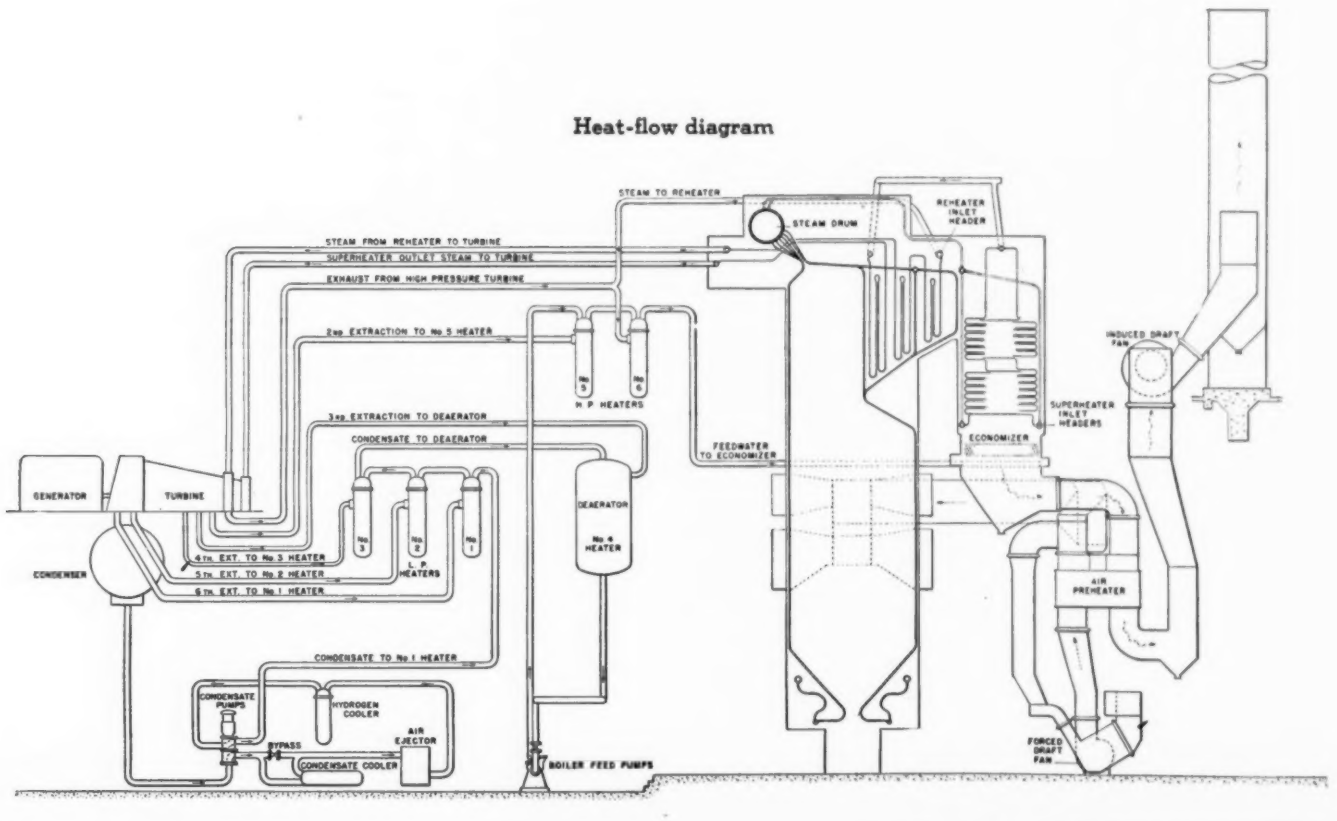
The two discharges of each condenser are combined into a single line which runs under the basement floor of the turbine room. The single lines from each condenser then leave the turbine room and rise to cross the dike just under its roadway where again the system is aided by a second siphon of 25.33 ft. From the high point of this siphon the water is conveyed vertically downward into a seal pit and over an adjustable weir where it discharges into the Po River downstream at the new intake structure.

Circulating and Condensate Pumps

The river water is pumped by two vertical single-inlet-propeller pumps, each capable of delivering 12,000 gpm and driven by a 250-hp motor at 540 rpm.

Two vertical re-entry booster-type condensate pumps serve each unit. When the turbine is operating at full load, water in the condenser hotwell is pumped by the two condensate pumps at a temperature of about 86 F through the condensate cooler, air-ejector condenser and hydrogen coolers and is then returned to the booster section of the condensate pumps. The temperature of

Heat-flow diagram



the water as it leaves the booster section is about 93 F. It is pumped at a pressure of 150 to 200 psig and delivered to the continuous blowdown heat-exchanger, thence to the No. 1 drain cooler from which it is discharged at a temperature of about 100 F.

The water then passes through low-pressure heater No. 1 where the temperature is raised to about 107 F, the heat being supplied from the sixth extraction of the turbine at a pressure of 3.5 psia and a temperature of 150 F. The condensate next flows through low-pressure heater No. 2 where the temperature is increased to 140 F with heat supplied from the fifth extraction at 10.6 psia, 295 F. The heat picked up by the water while passing through No. 3 low-pressure heater is obtained from the fourth extraction steam at a pressure of 23.5 psia and 420 F.

Deaerator

The deaerator of the spray type, has a capacity of 476,000 lb per hr. It operates at a normal pressure of 48.2 psia and has an active storage capacity of 780 cu ft. The main supply of water to the deaerator is from the condensate system, but water is also received from the high-pressure-heater drains at about 290 F. The deaerator receives steam from the No. 3 extraction nozzle of the turbine at approximately 48.2 psia and 558 F. Within the deaerator, the steam and water are in direct contact. The deaerated water collects in a storage space from which it flows to the boiler feed pumps, an overflow connection being provided in the deaerator from which any excess of condensate flows to the condensate storage tank.

Boiler Feed Pump

Two Worthington motor-driven boiler feed pumps have been installed for each boiler. Normally, one will operate and the other will serve as an emergency standby. The main feed pump is a five-stage horizontal, barrel, volute-diffuser type. At the design point the speed of this pump is 4040 rpm and it is driven through a stepup gear and hydraulic coupling. The motor driving the pump runs at 1480 rpm and drives a booster pump which supplies the main pumping unit. The hydraulic coupling provides a means of variable-speed operation to meet changes in frequency or load.

The boiler feed pumps force the condensate through high-pressure heater No. 5 in which the temperature is raised to about 354 F, heat being supplied by second extraction steam at 150 psia and 795 F. Finally, the boiler feedwater passes through high-pressure heater No. 6 where it reaches a temperature of about 438 F. It is heated with steam from the exhaust of the high-pressure section of the turbine at 380 psia and 690 F.

Check valves have been installed in each turbine bleed line with the exception of the fifth and sixth extraction leading to low-pressure heaters Nos. 1 and 2. The purpose of these check valves is to protect the turbine from a reverse-flow condition such as may be caused by the turbine throttle being tripped. The valves will also close if for any reason one of the closed heaters becomes flooded.

Elevation of the heaters is such that under normal conditions the shell drainage will flow by gravity from high-pressure heater No. 6 to No. 5. It, in turn, will drain to the deaerator. A shutoff valve and bypass is provided so that the drainage from high-pressure heater No. 6 can be fed directly into the deaerator. Low-pressure heater No. 3 drains will, under normal conditions, flow by gravity to low-pressure heaters Nos. 2 and 1, thence through a drain cooler and finally into the condenser. A shutoff valve and bypass is provided to permit the drains from low-pressure heater No. 3 to be fed directly into the condenser.

Provision has been made for the collection of continuous water samples for periodic chemical analysis.

Boiler Blowdown and Water Storage

In order to maintain the desired boiler water concentration, each boiler is provided with a continuous blowdown. This water, at about 1600 psi, is allowed to flash to a pressure of less than 150 psi within a flash tank, the drains from which are cooled before being discharged.

A freshwater-storage is provided for each boiler, of a capacity sufficient to hold all of the water normally used in the boiler. Motor-driven pumps handle the water to and from the boilers as required. These large tanks are used to store the boiler water during the shutdown period each year as the boilers will be drained and opened for free air circulation while out of service.

Cooling-water System

A recirculating cooling-water piping system distributes a supply of cooling water for bearings, plant air conditioning, turbine oil coolers, air-compressor coolers and other miscellaneous uses. This system involves three motor-driven pumps, two service-water coolers, a 72,000-gal service-water tank and network of necessary piping, valves, etc. The pumps discharge through coolers, giving up heat to the river water, which is supplied by the main circulating water pumps. The makeup to this system is obtained from well water which has been softened by passing through sodium zeolite equipment. This water is further treated with chromates to prevent corrosion.

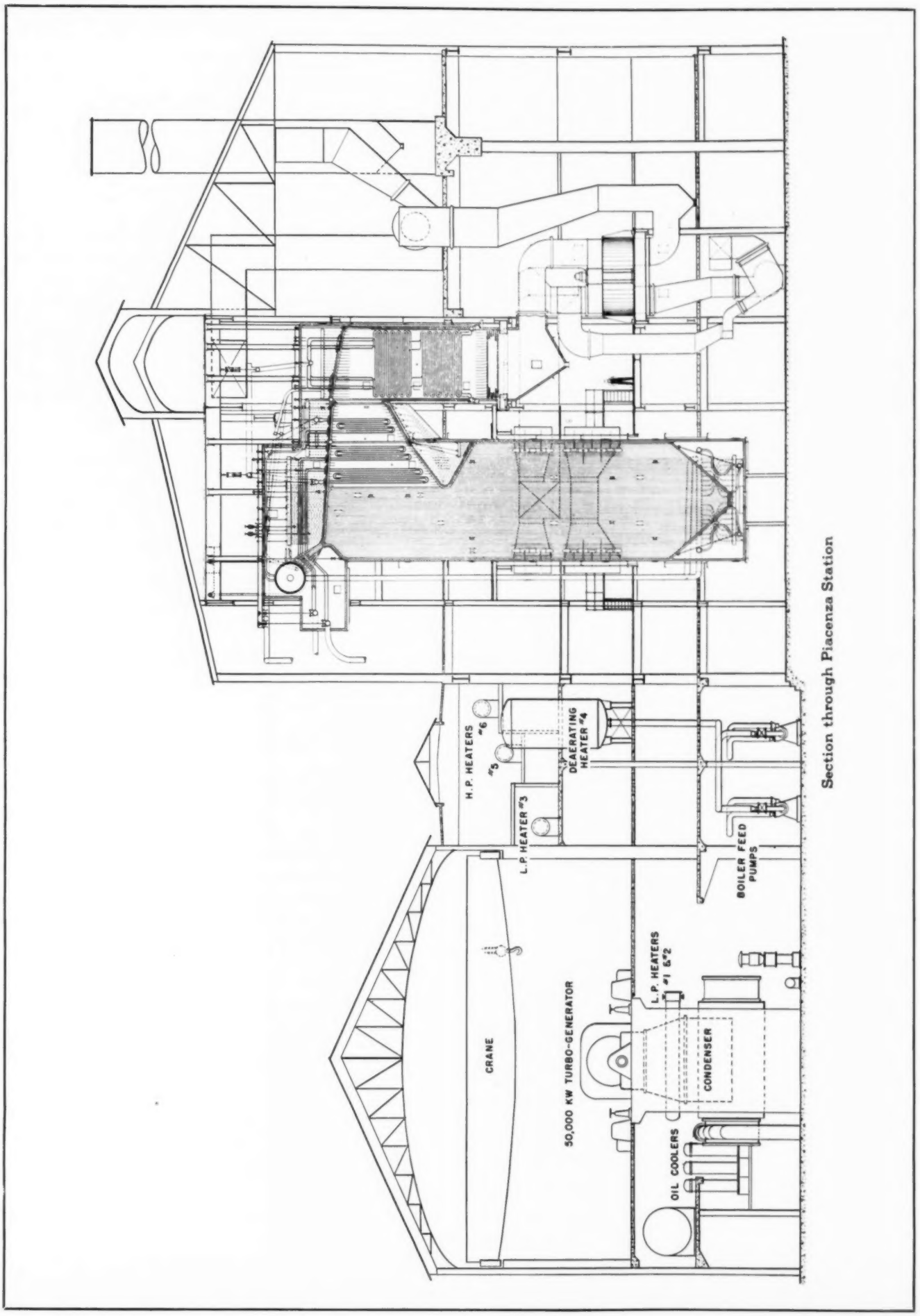
Well-Water System

To supply cooling water for circulating pumps, service water pumps, condensate pumps and provide makeup to the gland-seal tanks and on occasion the condensate storage tank as well as emergency cooling to the existing substation transformers, a system consisting of well-water pumps, a well-water storage tank of 15,000 gal capacity and connecting piping and valves has been furnished. The raw well water is passed through a sodium zeolite unit and softened before it is used for the above-mentioned services or stored in the well-water storage tank

Water-Treating Equipment

Water-treating equipment provides boiler makeup by passing well water through a demineralizing system. The raw well water is pumped to an elevated storage tank, from which it passes a cation exchanger and a degassifier, to a wood-stave storage tank. This partly treated water is then pumped through an anion unit to either of two treated-water storage tanks from where it flows by gravity to the condenser hotwells of the respective power generating units. The operation is completely automatic. Regeneration of the exchangers is initiated at the proper time and proceeds automatically. Levels in the various storage tanks are automatically controlled.

The treated water should have a maximum conductivity of 3.0 micromhos after corrections have been made



Section through Piacenza Station

for dissolved gases such as CO_2 and NH_3. The total net output of the demineralizing plant is about 170 gpm and the cation unit has a minimum exchange capacity between regenerations of 1730 KGR, while the anion unit has a minimum exchange capacity between regenerations of 1350 KGR.

Cooling-Water Makeup

In addition to the demineralizing equipment, a sodium zeolite unit provides makeup to the recirculated cooling water system. This unit consists of a vertical, cylindrical tank which is furnished complete with automatic and semi-automatic controls, meter, styrene resin, brine storage tank and saturator, brine measuring facilities, ejector and other appurtanances. The total net output of the sodium zeolite unit is 15 gpm and the minimum capacity between regenerations is about 432 KGR, expressed as equivalent calcium carbonate. Well water from the same storage tank used for the demineralization system flows through the sodium-regenerated exchanger to the storage tank of the recirculated, cooling water system. This unit also supplies soft water for making up the regenerant solution for the anion exchanger used in the demineralization system. Operation of this equipment, as in the case of the demineralization system, is completely automatic with provision to manually initiate regeneration, or to operate the unit manually in the event of power failure.

Chlorinating Equipment

Two program, semi-automatic chlorinators have been installed for treatment of condenser cooling water. The chlorine solution is fed to five points of application, one in each intake tunnel and also one point in the 20 in. river-water line serving the condensate and service-water coolers. The chlorinators are of identical design and of equal capacity, arranged so that one is in service while the other serves as a spare. Each point of chlorination is dosed intermittently and in rotation, in accordance with a predetermined time cycle. Additional controls are provided for manual operation. The normal demand for chlorine consumption is expected to be five pounds of chlorine gas per one million pounds of river water. However the equipment supplied is sufficiently flexible to permit increasing the rate of feed, as well as the length of application.

Each of the two chlorinators have a maximum capacity of 2000 lb per day, while the average estimated operating rate for each unit is 1200 lb per day. Control equipment consisting of a program clock, timers, pilot valves, etc., provide for the automatic cycle of dosing while the selection of feed rate is under manual control.

Chemical Treatment to Boilers

For the chemical treatment of boiler water, two duplex pumps for feeding sodium phosphate solution to the drum and two duplex pumps for feeding either caustic soda or sodium sulfite solutions to the boiler-feed line have been provided complete with chemical feed-tanks, controls and necessary appurtenances. The sodium-phosphate pumps are arranged so that two of the units take their suction from one common storage tank containing three per cent solution of anhydrous disodium phosphate or an equivalent concentration of another phosphate salt. Both sides of one of the pumps discharge through an individual pipe-line to boiler unit No. 1, and both sides of the other pump discharge through another pipeline to boiler unit No. 2. Interconnections are provided. The feeding of the phosphate solution is intermittent and controlled semi-automatically in accordance with a predetermined time cycle. Each injection of phosphate solution is followed immediately and automatically by a flow of soft feedwater or condensate through the pumps and pipelines to flush out the residual chemical solution and avoid plugging.

The sodium sulfite-caustic soda pumps are arranged so that one pump is connected to a storage tank containing sodium sulfite solution, having a concentration of not more than 3 per cent. One side of the duplex pump feeds the sulfite solution through an individual pipeline to the discharge line from the boiler feed pumps of unit No. 1. The other side feeds the solution through another pipeline to the discharge line from the boiler feed pumps of unit No. 2. A second pump is connected to a storage tank containing caustic soda solution with a concentration of not more than 3 per cent. One side of this duplex pump feeds caustic solution to the discharge line from the boiler feed pumps of unit No. 1 and the other side feeds the solution to the discharge line from boiler feed pumps of unit No. 2. The sulfite and caustic storage tanks are interconnected so that either may be used for feeding a mixture of either chemical to either unit by means of a single duplex pump.

In any case, the chemicals enter the respective discharge lines from the boiler-feed pumps after boiler feedwater for the desuperheaters has been taken from these lines.

Oil Conditioning and Hydrogen Cooling

Each of the main turbine-generators is fully equipped with an oil-conditioning unit, by means of which the lubricating oil can be maintained in good condition. This is designed to handle the modern double-inhibited lubricants. Each conditioner unit, in addition to the usual filters, comprises tanks of sufficient capacity to hold all of the oil assigned to the main turbine unit. During idle periods, the oil can be completely drained to the tanks for storage.

A hydrogen-cooling system, complete with apparatus for the automatic control of hydrogen density, water and oil vapor content, has been installed with each main generator. The hydrogen pressure can be maintained as high as 30 psig, but it is expected that the generators will be operated normally, with hydrogen pressure held between 5 and 15 psig.

Power for Auxiliaries

The equipment installed for this purpose includes electrical switching and transformer facilities. Electric power for driving the auxiliary apparatus is available at 3000 and 380 volts on separate buses for each main unit. These are electrical cross-connections to facilitate starting either of the main power units. A normal frequency of 50 cycles cannot always be maintained on the Edison system during the first few years of operation and consequently all auxiliaries are designed to deliver full rated capacity at a frequency of 46 cycles.

The installation was engineered by Gibbs & Hill, New York consulting engineering firm.

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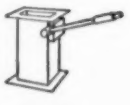

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Utilization of Low-Grade Coals for Power Generation

These excerpts from a paper, presented at the 65th Anniversary of the Association des Ingénieurs Électriciens sortis de l'Institut Électrotechnique Montefiore at Liege, discuss the utilization of low-grade coals with reference to the effects on overall boiler performance of ash content, ash fusibility, coal-swelling properties, sulfur content, moisture and grindability.

By RICHARD C. COREY* and JAMES W. MYERS†

THE burning of low-grade coal appears inevitable if conservation and national economy are to be served. The most-effective utilization of coal would be achieved by using the better grades of high rank coal, either as-mined or cleaned, only for chemical or metallurgical purposes. Then the refuse from cleaning plants and the poorer grades of coal direct from the mine could be burned for power generation.

Central-station and coal-mine power plants are the logical places to use this low-grade fuel, owing to their capacity for consuming large tonnages and to their past experience in solving other combustion problems in cooperation with furnace designers.

Ash Content

High ash content is probably the only property that can be used to judge the quality of coal, irrespective of the method of firing. It is true that coal very low in ash may be unsuitable for some methods of firing, such as on a traveling grate where ash is necessary for protection of the grate bars. However, low-ash coal is highly desirable for many other purposes.

High ash content requires the transportation and handling of larger quantities of material, owing to the reduced heating value, thus increasing the costs of these operations. Since the quality of coal is declining gradually with time, coal that was once considered of doubtful quality is now accepted as suitable for power generation. Generally, coal of about 20 per cent or more ash would be considered low-grade today in the United States.

Ash composition is important in its relation to ash-fusion characteristics. The relative amounts of silica, alumina iron, lime and magnesia in the ash exert a pronounced effect upon temperature, or temperature range, where clinkering, slagging or other changes occur in the physical properties of ash.

Low ash-softening temperature is an undesirable property of fuel when burned in fuel beds or in dry-bottom, pulverized-fuel furnaces. On the other hand, excessively high ash-softening temperatures would be undesirable for slag-tap and cyclone furnaces. In this respect, the viscosity of the ash in the fluid range may be as important as the fusibility.

Sulfur

Sulfur in coal is undesirable from the standpoint of metal corrosion and air pollution, particularly when present in concentrations exceeding about 4 and 5 per cent. Since the sulfur is associated with iron, high sulfur will usually denote low ash-softening temperatures, and, therefore, affect the quality of the fuel as discussed previously.

Except for coals from the Central States, run-of-mine coals in the United States generally contain less than 4.0 per cent sulfur. European coals, as a rule, contain less sulfur than American coals and therefore should offer fewer problems due to it. However, mine and washery refuse from any source may be high in sulfur, since the sulfur, in the form of pyrites, will be present in the denser fractions of the fuel.

Moisture

Since moisture dilutes the coal substance, and therefore lowers the heating value, a bituminous coal with high moisture content may be undesirable for certain purposes. This is particularly true of slurry which is fine bituminous coal recovered from the water of coal-cleaning plants and contains 25 to 40 per cent moisture and up to 20 per cent ash. By comparison, the better grades of deep-mined bituminous coal in the United States contain less than 5 per cent moisture as mined.

The effect of moisture on the quality of ranks of coal other than bituminous should not be considered. The best-quality lignite and brown coal, for example, inherently contain moisture to the extent of 35 to 50 per cent or more. Similarly, all anthracite used for generating steam contains a consistently high moisture, owing to the method that is employed in preparation and cleaning.

A limited amount of moisture in coal may be desirable under some circumstances. The burning of fine coals on grates may be improved greatly by moistening with steam or a water spray. The moisture causes the smaller particles to agglomerate, resulting in a more porous bed through which the combustion air penetrates more readily without formation of "blow holes."

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Size Distribution

Since pulverized-fuel-fired plants can handle fuel of any size, size distribution of the raw coal is unimportant The only effect of very fine sizes is a slight benefit resulting from the reduction of pulverizing costs.

However, fuels of certain size consist may be undesirable when burned on grates. The spreader stoker, for example, requires a range in particle size with a top size of $^3/_4$ to $1^1/_4$ in. and coal fine enough to sift through the grate bars would be unsatisfactory on a traveling grate.

Grindability

Although grindability is not important in coals burned on grates after a minimum of size reduction or with no preparation at all, coal of very low grindability would be undesirable for use in a pulverized-coal-fired furnace owing to the high power requirements and maintenance costs of pulverizing equipment. Coal dealer's associations recommend a lower limit of 45 to 55 Hardgrove for the grindability of bituminous coal in the United States.

Importance of considering low-grade coal

The reserves of the best-quality coal are being depleted gradually in many parts of the world. In Pennsylvania, for example, the Pittsburgh seam, which has supplied the best-quality coking coal for over 50 yr, is nearly exhausted.

Increased mechanization of mines has resulted in a decrease in quality of coal as it is delivered to the surface, owing to inclusion of more rock and shale and to production of greater quantities of fine coal or dust. Although the ash content of such coal may be decreased by cleaning this adds to the cost or may even be impossible, owing to shortages of production equipment during times of national emergency.

The increased production of strip-mined coal is another factor influencing overall quality of coal on the market. Strip mining is a rather important operation in times of high fuel consumption rates, since the supply may be augmented readily with a minimum of delay in obtaining production equipment.

With the growing scarcity of premium fuels, the resulting general rise in coal prices will make the use of low-grade coal attractive from an economic standpoint, even when better fuels are available.

The problem may become one of a choice between three different fuels: (*a*) coal as produced in the mine, without further treatment, (*b*) coal upgraded by cleaning and (*c*) the refuse from cleaning processes. Some engineers believe that burning the coal as mined is more economical than cleaning before use. This procedure would be more efficient in the utilization of the heat energy in the coal, since even the best preparation methods leave considerable combustible in the refuse. Although the economics do not favor its use at present, a tremendous supply of potential boiler fuel is available in existing gob piles and in the daily output of bituminous-coal-cleaning plants. Frequently this material contains as much as 50 per cent combustible. Large tonnages of low-grade anthracite are also available. One public utility firm has purchased a number of silt piles containing 55 to 90 per cent combustible, which will be held in reserve until economics favors their use.

Another factor that should be considered is the trend toward smoke-control legislation with reference to burning gob piles. It is perhaps too early to estimate the effects of such laws on the cost of refuse disposal; but it is certain that any increase of disposal costs will favor the utilization for fuel of either the refuse, or of raw coal without preparation.

Pulverized-Fuel Firing

The maximum capacity of stoker-fired boilers in the United States is around 300,000 lb of steam per hr, whereas a number of pulverized coal units generate over one million lb and even larger units are now being designed.

Although it is possible to use pulverized-coal firing at steam rates as low as 50,000 lb per hr, it is conceded generally that stokers will provide for lower overall investment and operating cost at rates below 200,000 lb per hr.

The dry-bottom furnace is probably the most versatile type of equipment with respect to grade and rank of coal. A number of installations are burning successfully coals ranging from lignite to anthracite and containing ash up to 50 per cent or more. Coal with ash-softening temperatures as low as 1900 F are handled readily, and some designers are confident that coal of any known ash fusibility may be burned if the unit is designed properly.

The slag-tap furnace was developed to burn coal having low ash fusibility and to remove a portion of the ash in a form more convenient for disposal than the fine dust from hoppers of dry-bottom furnaces. The relatively high temperatures required for melting the ash is an advantage, since it provides for higher heat-transfer rates. Tangential or turbulent burners are required to maintain high temperatures at the bottom of the furnace for satisfactory slag flow. The slag-tap furnace is similar to the dry-bottom type in size range and in the type of fuel which it can handle, except for limitations imposed by ash-softening temperatures exceeding about 2600 F. Near the upper limit of ash-softening temperature the unit loses flexibility with respect to load variations.

Cyclone Furnace

The cyclone furnace is a comparatively recent addition to the field of coal-burning equipment. The principle of operation is to provide for relative motion between the air and the fuel. Coal crushed to $^1/_4$-in. and smaller is introduced tangentially into the burner, where it adheres to the slag-coated walls and is scrubbed by the secondary air. The hot gases leave the front of the burner and pass through the primary furnace, through a screen of water tubes and into the secondary furnace. Most of the ash melts and drops into the primary furnace where it is removed. About 10 per cent of the coal should pass a 200-mesh screen to assist in ignition.

Like the pulverized-coal-fired slag-tap furnace, the cyclone will burn coal very high in ash and with ash-softening temperatures below about 2600 F. However, it is believed that some limitations should be observed in volatile matter and moisture content, although the full possibilities of the unit in this respect have not yet been explored thoroughly.

The manufacturer claims that only about 7 to 10 per cent of the coal ash is carried out of the furnace in the form of dust, but some of this advantage is lost by the tendency of certain deposits, which originate from the mineral matter in the coal, to form on superheater tubes. The smaller physical size and space requirements of the cyclone furnace are an advantage.

Spreader Stoker

The spreader stoker combines to a certain extent the characteristics of two methods of burning. A large percentage of the volatile matter is released, and the smaller particles are burned completely in suspension, while the larger particles are burned in a solid fuel bed. It was developed primarily to burn lower grades of fuel with high ash content and low ash fusibility. It can handle, with equal facility, everything from lignite to semianthracite, and since the coal particles are preheated while they are in suspension in the furnace, thus destroying the caking properties, the spreader stoker is very effective for burning coals with a high free-swelling index.

At present the largest units in the United States are of about 300,000 lb per hr capacity, the maximum size being limited by practical problems in connection with designing grates of over 600 sq ft in area. Dump grates can be used for steam capacities up to about 75,000 lb per hr. However, the continuous-discharge traveling grate is essential at high rates and is preferable at lower rates, particularly when the ash content exceeds 10 per cent.

About the only requirement for successful operation of the spreader is a range in coal-particle size to provide for proper distribution of coal on the grates. The upper limiting size is usually specified at $^3/_4$ to $1^1/_4$ in. Maximum efficiency of a spreader stoker unit burning any fuel occurs at an hourly burning rate of about 35 lb per sq ft, but good results have been obtained at rates up to 50 lb.

Traveling-Grate Stokers

Traveling- and chain-grate stokers will both be included in this category, since the combustion process is the same in either one. The principal difference is construction of the grate surface The surface of the chain grate consists of links connected by pins to form a chain whereas the traveling-grate surface consists of sections or keys supported on carrier bars fastened to the drive chains. The keys are designed with air passages to fit the particular fuel being burned.

The capacity of traveling grates is similar to that of the spreader. Units for generating up to 250,000 lb of steam per hr, with a grate area of 672 sq ft have been operated successfully. The traveling grate is suitable for burning low-grade anthracite, coke breeze, lignite and bituminous coals whose free-swelling index does not exceed about 6. The chief advantage of the traveling grate is its ability to burn low-grade anthracite and coke breeze. The size consist and ignition characteristics of these fuels are not well-suited for use with the spreader stoker, and the low grindability of coke breeze precludes its use for pulverized-fuel firing. The only limitations on ash content are that about 5 per cent or more ash must be present to protect the grate from overheating.

With bituminous coal, which contains easily ignited volatile, an arch is provided over the front of the grate. With anthracite and coke breeze, which contain very little volatile and are difficult to ignite, the arch is at the rear of the grate and extends over half the width of the furnace toward the front wall. The underfire air is divided by compartments (any number up to 8), and the air pressures are regulated in the various sections so that the maximum occurs under the arch. The finer sizes of coal burn partly in suspension, the high air rate under the arch carrying the incandescent particles forward into the green fuel to provide ignition. Frequently, air jets are supplied in the nose of the arch to increase turbulence in the throat of the furnace and direct the coal particles downward toward the front wall. This assists in better mixing of combustible gases with oxygen and in reducing the amount of fines carried out of the furnace by the flue gas. Lignite is burned in a furnace with a rear arch because its ignition characteristics on the traveling grate are similar to those of anthracite. The high moisture content contributes to slow ignition; and, although lignite is high in volatile, the heating value of the volatile is much lower than that of bituminous coal.

Frequently, layer firing is used with the traveling grate to burn low-grade coal in conjunction with fuel of better quality. For example, coal or coke breeze too fine to burn directly on the grate can be fired on top of a layer of coarser coal. An adjustable divider in the stoker hopper controls the relative thickness of the layers.

The maximum efficiency of traveling-grate stokers occurs at hourly burning rates between 25 and 35 lb per sq ft, depending upon the fuel.

Underfeed Stokers

The consensus of engineers today is that a better and more consistent grade of fuel is required for underfeed burning than for any other type of combustion. Furthermore, high maintenance costs and lack of flexibility in operation have contributed to a decline in its popularity.

Gasification

Inasmuch as many operating problems in coal-fired furnaces are caused by the ash in the coal, several schemes have been proposed for gasifying the coal completely in equipment external to the boiler and burning the relatively clean gas in the furnace. In this manner problems associated with ash deposition would be largely avoided.

The Szikla-Rozinek producer built integral with a furnace, has been used for gasifying fine coal in suspension and for subsequent burning of the gas in the furnace. Several commercial-size units of this type have been operated in Hungary. By means of a spreader stoker the green coal is introduced into a stream of coke circulating between two chambers separated by a dividing wall. Hot gases passing through the second or carbonizing chamber destroy the caking properties of the raw coal and convert it to coke. The coke is moved to the gasification chamber by a mechanical ram, where it is partly gasified, the remainder being carried back to the carbonization chamber by the gas stream. The ash is melted and settles to the bottom of the gasification chamber, where it is removed through a rotating cylindrical grate, which also admits the air. The hot, gaseous products, comprising producer gas and the volatile matter from the coal, pass into the furnace, where they are burned. The chief disadvantage of the system is in obtaining temperatures high enough for removing the slag countercurrent to the incoming air.

The Flesch-Winkler down-draft producer has also been recommended for the purpose. Its operation is a periodic process in which the fuel is added and the ash removed from the fluidized bed during the "blow" cycles and water gas is produced during the "run" cycles. The advantages claimed for this process are: (1) it is capable of handling a wide range of coal size, either caking or noncaking; (2) it is independent of the quantity and fusi-

bility of the ash in the fuel; (3) it has high gasification rates, (4) it has low combustible loss in the residue; and (5) it results in low exit-gas temperatures, permitting easy cleaning of the gas.

Underground gasification also may be a possibility in the future, but considerable development work will be required before it is feasible.

The Combustion Research Section of the Bureau of Mines, U. S., Department of the Interior, has conducted an investigation on the gasification of coal in a cyclic process in a small laboratory furnace. During the "blow" period the bed was expanded sufficiently to permit limited motion of the fuel particles, and fresh coal is added. Owing to the higher density of the ash particles, they settled downward through the expanded bed and deposited in a solid porous mass on the grates. During the "run" period steam was passed through the bed at a velocity less than that required to lift the fuel. On the basis of this work, which is not yet published, the Bureau of Mines proposed commercial-size equipment for the production of water gas.

Another investigation carried out by the Bureau of Mines was on the gasification of Rhode Island meta-anthracite in a continuous-slagging gas producer. This coal has such poor quality as fuel that it cannot be burned satisfactorily in any of the conventional combustion equipment. It is not only high in ash (approximately 40 per cent) but is of such high rank that it contains very little volatile matter and the fixed carbon is graphitic in nature. It was found possible to maintain combustion in a slagging producer if the air was preheated to about 800 F. For this process the high ash content was an asset, since it was used for the production of mineral wool.

Problems in Burning Low-Grade Coal

Engineers differ as to the effect of low-grade coal on capacity and availability of furnaces. Some believe that the combustion volume of pulverized-coal furnaces should be designed very liberally, with hourly heat-release rates as low as 9000 Btu per cu ft. With stokers they recommend a maximum burning rate of about 25 lb per sq ft when burning high-ash coal. However, others assume that heating surfaces can be kept as clean with low-grade coal as with higher-quality fuel and see no relation between ash content of the fuel and the capacity and availability of the furnace and boiler. They base their designs upon the relation of the area of heat-absorption surfaces to furnace-exit-gas temperatures as affected by the ash-fusion characteristics of the coal. This practice is the same as for high-grade fuel and leads to hourly combustion rates of up to approximately 20,000 Btu per cu ft in pulverized-coal furnaces or 40 to 50 lb per sq ft on stokers.

Traveling grates generally need to be designed for higher speeds to insure the necessary capacity without excessively thick fuel beds.

All engineers agree on the adverse effect of high-ash coal on the capacity, availability, and maintenance of pulverizers and coal- and ash-handling equipment. Pulverizer capacity and power requirements may suffer simultaneously from two conditions. High ash content requires that a greater quantity of material be handled; and lower grindability, frequently accompanying high ash, requires increased grinding capacity. Thus the overall increase in capacity and power required would be greater than that indicated by increased ash alone.

Low grindability is responsible also for increased wear and maintenance of pulverizers. The Hardinge-type ball mill is less susceptible in this respect than are the bowl mill, or the ball-and-race mill. Even coke breeze may be ground in this mill but is not recommended, since the rate of wear will be about eighteen times the rate when grinding hard bituminous coal. Although the power requirements of ball mills are considerably higher than those of the bowl mill, their maintenance cost is affected less by grindability. However, other engineers prefer to use the bowl mill or the ball-and race mill, regardless of grindability, and are willing to accept increased wear and higher maintenance costs caused by coal difficult to grind.

One of the harmful effects of wear on pulverizers is the increased outage time necessary for repairs. The bin-storage system and standby pulverizers are recommended by some engineers as a solution to this problem. They point out that, with the bin system, only the pulverizer is taken out of service, whereas in the direct-firing method some of the burners will be idle as well. It should be remembered that, although wear is less damaging to ball mills than to other types of pulverizers, the exhaust fans of all pulverizers are equally susceptible to the effects of wear caused by coal of more abrasive nature.

The capacity of coal conveyors and feeders, ash-disposal systems, and dust collectors must be increased in proportion to the quantity of material to be handled, as the ash content of the coal increases. Larger induced-draft fans may also be required to overcome additional draft loss in the dust collectors.

High moisture content will also tend to reduce the capacity of pulverizers and to cause trouble with other coal-handling equipment, unless special precautions are taken.

Carbon Loss

High carbon loss, particularly in the fly ash, generally occurs when pulverized coal high in ash content is burned. The exact relationship is not known with certainty, but it is believed to be influenced by ignitability of the coal and the relative proportions of inherent and extraneous ash. Finer grinding is recommended to reduce this carbon loss; in general, the higher the ash content the finer the coal should be.

High carryover of unburned carbon occurs with spreader stokers when burning any kind of fuel, and reinjection of the cinders is almost universal practice.

High carbon loss in the ashpit may occur when burning anthracite on traveling grates if the particle size is too large. The problem would be more serious with high-ash coal, owing to the greater stoker speed required. The solution is to use finer coal and to adjust the air pressure properly in the rear compartments to carry the unburned fuel toward the front of the furnace. When burning very fine coal on grates it is sometimes helpful to moisten the fuel to promote agglomeration of the fines.

Clinkering in Fuel Beds

Clinkering is usually caused by uneven air distribution through the grates when coal of undesirable ash-softening characteristics is burned; it is not affected materially by the quantity of ash. The problem is most pronounced when coal of improper size consist is fired by spreader

stokers upon stationary or dump grates without air compartments. If the size of the largest particles is too great, the fuel bed resistance is relatively low at the rear of the grate. Also, the front of the grate will have little air resistance, since the fine particles will burn in suspension before falling to the grate. The result is that most of the air passes through the front and rear sections of the grate, and a deficiency occurs at the middle section. This lack of air causes a reducing condition and lowering of the ash-softening temperature. In addition to the difficulty of removing the clinker, overheating and damage to the grate may occur because of the low air rate in this center section.

The top size of the fuel should be limited to about $^3/_4$ in. to obtain satisfactory distribution of air through this type of grate. Clinkering is less serious with traveling grates under spreader stokers, since these are compartmented for regulation of the air distribution, and movement of the grate tends to make the fuel bed resistance more uniform.

Another difficulty caused by the uneven air distribution, although unrelated to clinker problems, is gas stratification and uneven gas temperatures at the furnace outlet. This results in more-severe tube slagging for the same average furnace-outlet temperature and in poor temperature distribution across the superheater.

Slag and Ash Deposits

Some engineers prefer the dry-bottom furnace for all applications of pulverized-coal firing, regardless of the ash-softening temperature. Others believe the slag-tap furnace is the more appropriate design for coals of low ash-softening temperature. However, it is less versatile than the dry-bottom furnace and should be specified only when a supply of coal having suitable ash-fusion properties is assured for the economic life of the unit—that is, at least 20 yr.

Ash particles carried out of the slag-tap furnace by the gases, amounting to 50 per cent or more of the ash in the coal, can be in a molten or soft plastic condition when they reach metal surfaces in the superheater and boiler passes. This is responsible for accumulations on tube surfaces, which disturb the flow of gases and reduce the rate of heat transfer.

Deposits in the boiler passes of dry-bottom and stoker-fired units also are caused by molten or plastic ash particles carried by the gas. Although these furnaces are designed for average conditions, deviations from the mean gas temperature may occur, with the result that gas temperatures are above the average in some areas at the furnace outlet. When the ash deposit becomes thick enough to give a high temperature gradient through the deposit, the rate of build-up on the hot, sticky surface can be comparatively rapid in the dry-bottom unit owing to the high concentration of dust in the flue gas. Likewise, the properties of low-grade coal are apt to vary widely, and furnaces designed for the average fuel composition would be subject to fouling by the portions of the fuel having the lower ash-softening temperatures.

In some respects, the ash deposits in dry-bottom furnaces are less objectionable than those in a slag-tap furnace. Owing to a more friable nature, they tend to shed from the walls more easily during load changes and respond more easily to lancing. In furnaces where temperatures are very high, as in slag-tap and cyclone furnaces, volatilization of alkalies from the ash and slag results in deposits that adhere tightly to furnace, boiler and superheater tubes. Such deposits are generally difficult to remove.

Every consideration should be given to supplying adequate soot blowers when burning coal of high ash content. Also, all parts of the gas passages beyond the furnace exit should be accessible for hand lancing when the soot blower cannot cope with the situation, particularly in the case of the cyclone burner and the slag-tap furnace.

Often, low ash fusibility requires that dry-bottom furnaces be designed for gas temperatures that are too low to obtain the required superheat and reheat temperatures. The usual way to overcome this situation is to install radiant superheaters directly in the furnace. This complicates the ash-removal problem and necessitates careful location of soot blowers and adequate provision for hand cleaning. Such superheaters, unlike boiler tubes containing a fluid of uniform temperature, may be susceptible to damage if heavy local deposits cause uneven heat-transfer rates.

Another difficulty in connection with ash deposits occurs occasionally in the ash hoppers of dry-bottom furnaces. Ash of very low softening temperature may sinter and form clinker or stick to the water-cooled surface. One manufacturer solves the situation by the use of a hopper that is inclined at an angle to the axis of the furnace, so that the accumulated ash will be shaded from direct radiation from the flames.

Slag Viscosity

Use of low-grade coal should not cause undue operating difficulties related to the flow properties of slag, provided the effects of the viscosity of molten ash are understood and allowances made in furnace design for the wide variations in ash composition that occur with low-grade coal. It was mentioned earlier that the slag-tap and cyclone furnaces were suitable for coal having ash-softening temperatures below about 2600 F. Actually, the viscosity of the molten ash is the only property that is related to its flow characteristics, and accordingly, should be a more satisfactory criterion of successful operation at any particular temperature.

Slag viscosity not only influences the removal of slag from the furnace but also affects the heat-transfer rate through the furnace walls. The rate of heat transfer through the walls influences the temperature of the gas at the furnace outlet, which is an important factor used by designers. In this connection, it should be noted that the temperature of the preheated air will affect the temperature in the combustion zone and therefore will control the flow properties of the slag in that region of the furnace.

Ignition of Low-Grade Coal

Engineers do not agree on the relative ease with which various fuels may be ignited in different furnaces. When interest was first directed toward utilization of high-ash bituminous coals in pulverized-fuel furnaces, two requirements were considered essential to establish and maintain stable ignition—to provide generous refractory surfaces and to use long, quiet flames from burners mounted in the roof to provide the best opportunity for heat transfer to the incoming fuel and air. Refractory walls and arches were also considered indispensable in stoker-fired furnaces, and there are instances in literature where auxiliary firing of oil is recommended when coke

breeze or high-moisture anthracite is burned on traveling grates.

Some engineers still hold to many of these beliefs in varying degrees, but others favor the same type of equipment used for higher-grade coal; that is, with minimum refractory. One manufacturer has been successful in designing tangentially fired, completely water-cooled furnaces for burning pulverized bituminous coal containing up to 50 per cent ash. They also recommend water-cooled metal over the entire wall and arch surface of traveling-grate-stoker furnaces. Their opinion is that the coal can be ignited as easily by radiation from the flame or hot gases as by radiation from hot refractory, even when burning anthracite containing only 3 per cent volatile matter. With bituminous coal, overfire air jets are required to burn the volatile matter. Jets are not required for combustion of anthracite, but in the larger units they are useful for reducing carryover of cinders by directing them toward the fuel bed.

It is generally agreed that preheated combustion air is advantageous in promoting ignition of low-volatile, high-ash coal in water-cooled furnaces, although some designers do not believe it is absolutely essential. With stoker-fired furnaces the air temperature should not be so high that it endangers the grate material.

High-ash and low-volatile pulverized coals are more readily ignited when a fairly rich mixture of coal and primary air is used. However, this introduces problems resulting from transporting the coal to the burners with a relatively small amount of air. Generally, the bowl-type pulverizer has a greater latitude in the air-coal ratio when it is operated at a high percentage of its rated capacity. This suggests the need for very careful selection of pulverizer capacities, particularly for boilers designed for a wide range in rate of steam generation.

Where the air-coal ratio cannot be controlled adequately in the pulverizer, the bin-feed system is convenient, although in this case predrying of the coal may be required.

Corrosion and Erosion

Corrosion of relatively cool metal parts is related directly to the sulfur content of the fuel and occurs when the metal temperature is below the dew point of the flue gas. Since the dew point depends upon the concentration of SO_3 and water vapor in the flue gas, the higher sulfur coals will cause the most difficulty. It should be noted that the metal temperature is the governing factor rather than the gas temperature. Thus, corrosion of an economizer may occur in a relatively hot gas zone when the inlet feedwater temperature is low, yet the air heater may be operating safely in cooler gas, owing to the relatively high temperature gradient between air and metal.

Economizer corrosion may be prevented by designing the steam cycle so that the temperature of the feedwater entering the economizer is above the dew point of the flue gases. In some power plants, as many as seven stages of feedwater heating are used. In addition to preventing corrosion, this scheme provides for more reheat when the reheat cycle is used, and permits the use of higher preheat in the combustion air. Some designers claim that the overall efficiency of the unit can be improved by using higher feedwater temperatures.

Corrosion of air heaters may be prevented simply by designing them for higher temperatures of the gas discharged to the stack. This may be accomplished by designing the air heaters with less surface, by providing a bypass around the economizer for part of the flue gas, by recirculating hot air through the air heater, or bypassing part of the cold air around the air heater. The recirculation or bypass methods are of value when the sulfur content of the fuel supply is liable to change, since dampers in the ducts permit very accurate control of the stack gas temperature.

The extent of erosion of refractory furnace walls and boiler pressure parts depends upon the quantity of dust passing through the furnace, its physical properties and the velocity of the furnace gases. The quantity of dust will be affected by the burning rate, by the ash content of the fuel, and by the type of furnace. Thus, for any particular design of furnace, higher ash content of the fuel signifies greater erosion problems. Since the quantity and properties of the dust or cinders are more or less fixed, the only latitude of design which is open to the engineer is in the furnace-gas velocity. By designing all gas passages with generous proportions, he can keep the average velocity within safe limits.

Power-Plant Location

Use of low-grade coal presents more of a problem in locating a power plant than does the use of better-quality fuels. With the latter, it is cheaper invariably to ship the coal by rail or water to the load centers. However, with coal of low heating value or coal difficult to handle owing to fine size consist and high moisture content, it may be necessary to make a choice between the load center and the mining or preparation center. Such a choice will be based primarily upon economic factors.

In general, the cost of shipping the fuel and disposal of ash should be compared critically with the cost of transmitting electrical energy from the mine to the load centers. The relative costs of cooling water at the two locations will also influence the selection. Where cooling towers are necessary, the water costs will be higher than if an abundant source of river water is available. Usually, when the cooling-water problem is involved, it favors location of the plant at the load center. However, in some locations adequate water is available at the mine, and no problems in this respect are involved. Similarly, enough water is frequently unavailable at the load centers, and plant location does not alter the magnitude of a problem already present.

Air Pollution

The use of low-grade fuel with a high ash and sulfur content may aggravate air-pollution problems. In localities where rigid laws are in force, dust collectors and precipitators of greater capacity and higher efficiency will be required, particularly with pulverized-coal-fired furnaces and with spreader stokers.

High sulfur content in coal, in so far as it affects air pollution, is a more difficult problem. With the usual combustion equipment the sulfur gases cannot be removed and pass out with the flue gas. When concentrations are objectionable, it may be necessary to use additional coal cleaning to remove the pyrites or to locate the boiler plant in an area where these gases are less objectionable. In this case air pollution would take precedence over the economic considerations of plant locations.

Facts and Figures

The bituminous coals that are being mined today were formed during the Carboniferous Age which ended some 200 million years ago.

●

Oxidation of SO_2 to SO_3 under the influence of the sun's rays creates hydroscopic nuclei which increase fog formations.

●

Sweden is the first country to employ a transmission voltage of 380 kv. This is used on a line that runs from Harspranget to Hallsberg.

●

Currently crude oil production in the United States is reported to average about six million barrels daily.

●

If a sample of pulverized coal were magnified a thousand times, the smallest particles would appear about the size of a grain of sand and the largest like boulders nearly two feet in diameter.

●

The electric utilities, as a group, are the largest consumers of coal in the United States, their demand last year having amounted to approximately a fifth of the total output.

●

It has been estimated that a reduction of exhaust pressure in a condensing turbine from 1 to $^1/_2$ psia will reduce the coal consumption 4 to 5 per cent.

●

Typical corn-on-the-cob, as occasionally burned in some places, analyzes about 16.5 per cent moisture, 1.5 per cent ash, 11 per cent fixed carbon and 71 per cent volatile matter, with a heating value of about 8000 Btu per lb, on a dry basis.

●

When burning oils containing vanadium compounds, the relatively low melting point of the ash usually results in a thin sticky precoat of vanadium slag which leads to accumulations of sodium sulfate slag.

●

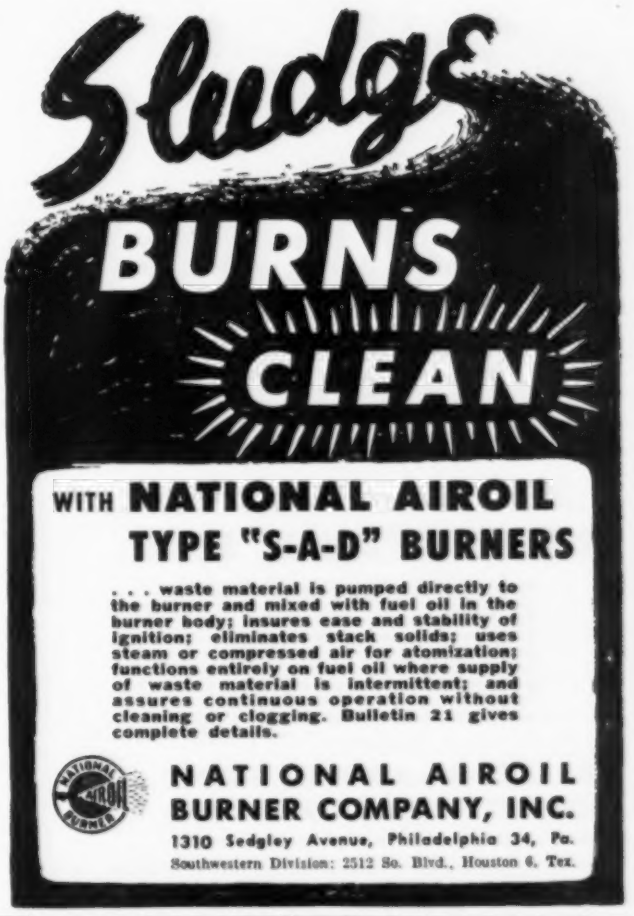
The Semi-Annual report of the Atomic Energy Commission, dated July 1952, states that the annual power consumption of its latest gaseous diffusion plant, to be built at a new site in Ohio, will exceed the 1951 electric comsumption of New York City.

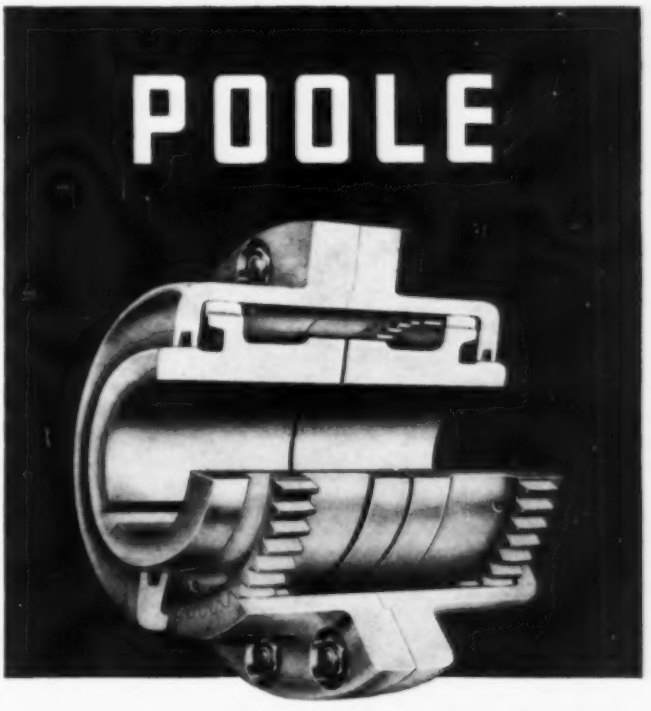
●

According to statistics compiled by Bituminous Coal Institute, there are approximately a million persons, engaged in the mining, selling and delivery of coal in this country, exclusive of those whose jobs depend upon the movement of coal.

●

The world's largest gas turbine plant is at Beznau, Switzerland. It has a total rating of 40,000 kw in two units, one of 27,000 kw and the other of 13,000 kw.


Sludge
BURNS
CLEAN
WITH NATIONAL AIROIL
TYPE "S-A-D" BURNERS
. . . waste material is pumped directly to the burner and mixed with fuel oil in the burner body; insures ease and stability of ignition; eliminates stack solids; uses steam or compressed air for atomization; functions entirely on fuel oil where supply of waste material is intermittent; and assures continuous operation without cleaning or clogging. Bulletin 21 gives complete details.
NATIONAL AIROIL BURNER COMPANY, INC.
1310 Sedgley Avenue, Philadelphia 34, Pa.
Southwestern Division: 2512 So. Blvd., Houston 6, Tex.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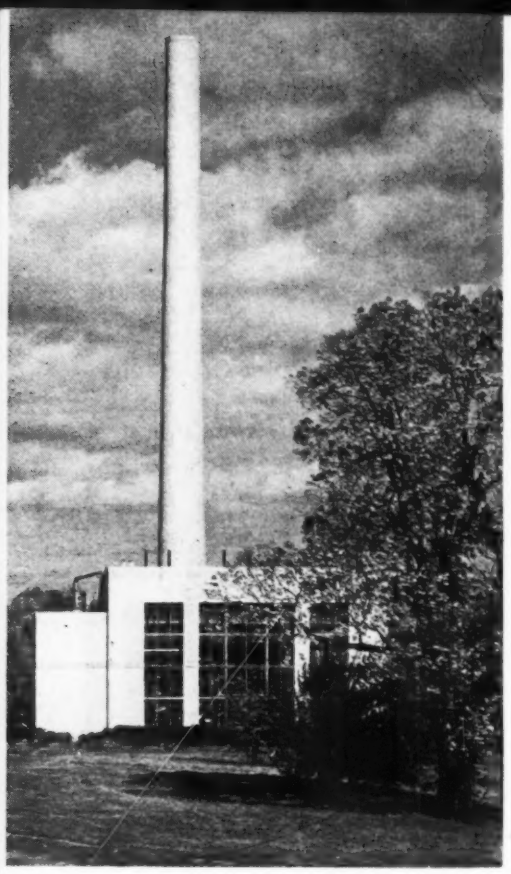
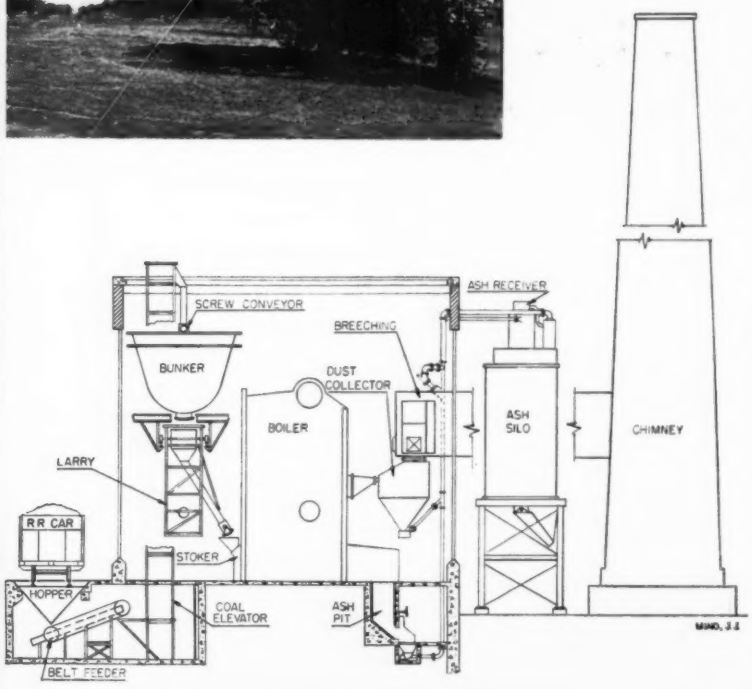
A COPY OF CATALOG GIVING FULL DESCRIPTION AND ENGINEERING DATA SENT UPON REQUEST.
FLEXIBLE COUPLINGS
POOLE FOUNDRY & MACHINE COMPANY
WOODBERRY, BALTIMORE, MD.

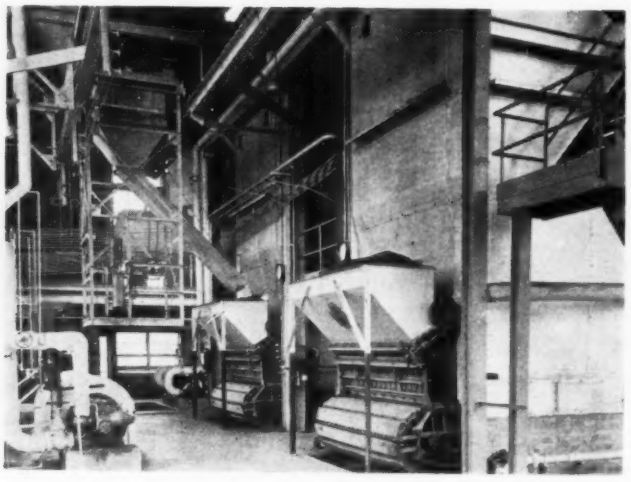


Modern Steam Plant at Villanova College

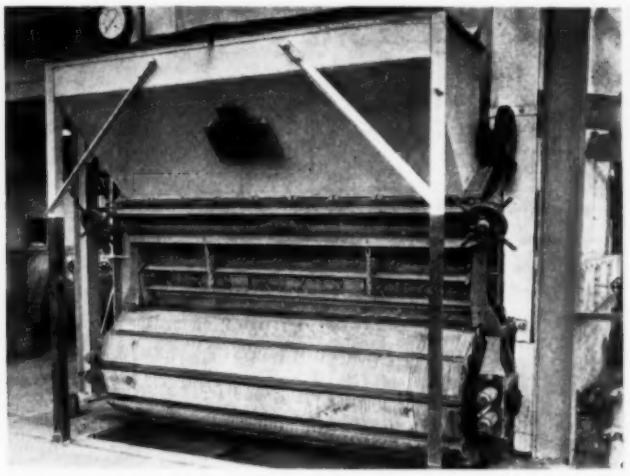
VILLANOVA College near Philadelphia, in common with other institutions located within easy reach of the anthracite regions of Pennsylvania, has found this solid fuel to be economical and convenient for steam generation. Therefore, its new steam plant built in collaboration with the Scranton consulting engineering firm of Gilboy and O'Malley has been designed to burn anthracite, including fine sizes recovered from Pennsylvania streams, on traveling grate stokers.

From the time of its founding in 1842 until the present, Villanova College had generally followed the practice of separate heating plants for each major building, although there were a number of interconnections. Following World War II the college undertook an extensive building and modernization plan, including an impressive new library, a fully equipped chemical engineering laboratory, and a building for specialized military training. To meet these needs as well as those of the enlarged student body which now totals more than 2600, a faculty committee headed by J. Stanley Morehouse, Dean of Engineering and George H. Auth, Professor of Mechanical Engineering, made a survey of the existing and anticipated steam requirements. Their conclusion was that a steam plant having a capacity of 60,000 lb per hr would serve the anticipated heating needs of the college.

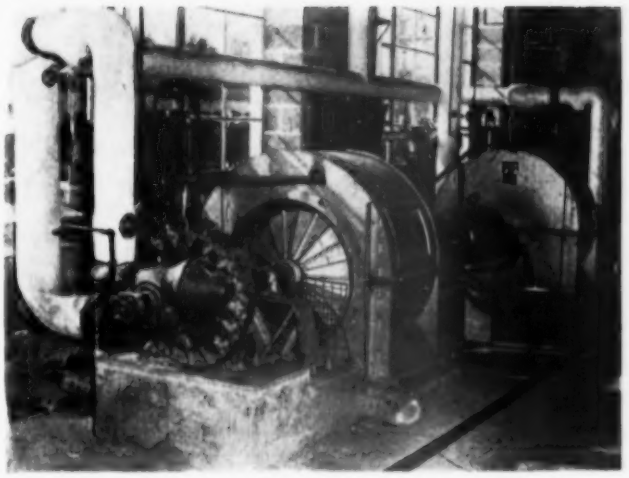




Traveling weigh larry which feeds coal from overhead bunker to stoker hoppers



Close-up view of traveling grate stoker showing coal hopper, control for adjusting fuel bed and windboxes



Forced-draft fans equipped with dual motor-turbine drives

Instrument panel board for automatic or manual boiler operation; pressure, flow, draft, temperature and CO_2 content may be read from this panel

As shown in the accompanying cross-section there is a 250-ton overhead storage bunker, from which a traveling weigh larry feeds coal to the hoppers of the Coxe traveling grate stokers. Seven bunker gates permit withdrawal of coal from all parts of the bunker, eliminating many of the possibilities of spontaneous combustion and storage compaction.

Two Combustion Engineering-Superheater Type VU steam generating units, each having a continuous rating of 30,000 lb of steam per hr at 125 psig, are installed. Overfire air is available through the rear arch, aiding the combustion of the anthracite on the Coxe stoker. Ash is dropped off the end of the traveling grate to the lower level 12 ft below the operating floor, where a steam jet ash conveyor pipe is provided for its handling.

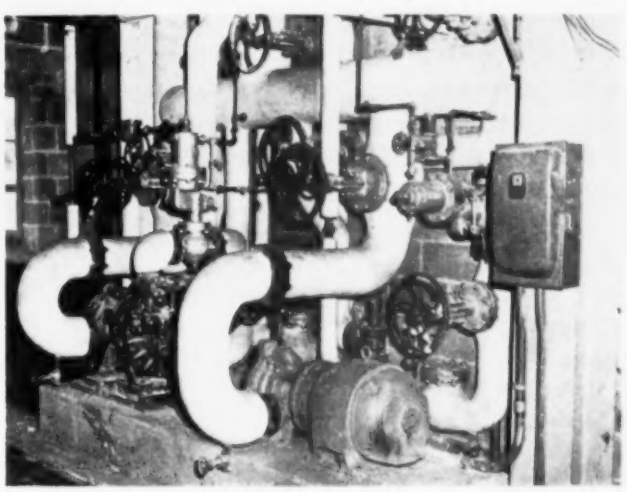
Auxiliary equipment is installed in duplicate, with both electric and steam-turbine drives. Draft is provided by a forced-draft fan and a 215-ft radial-brick stack. Gases from the boilers pass through dust collectors of the multiple-tube cyclone type.

The plant is located at the lowest point of the Villanova campus, allowing for gravity return of condensate from building heating. This condensate is collected in a vented surge tank located in the basement of the plant. A pair of booster pumps which cut in at different levels of the tank lift the water to a tray-type deaerating heater located on a platform fifteen feet above the operating floor. It then is supplied to the boiler by two feedwater pumps installed just below the heater on the operating-floor level.

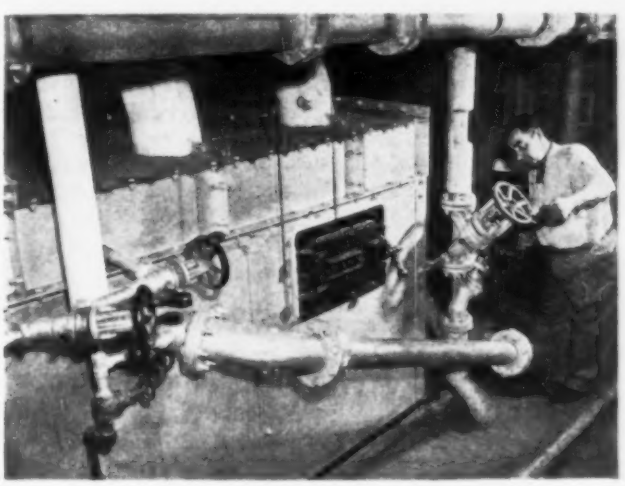
A central control panel provides the operator with information on plant performance. Pressure, flow of steam and water, draft conditions, and flue gas composition are among the quantities indicated or recorded on the control panel. Automatic combustion control provides for load division between the boilers.

The steam plant has yellow brick walls as exterior construction, with inside walls of cinder block. Provision has been made for living quarters for the chief operating engineer, showers and wash rooms for the operators and for a plant office.

COMBUSTION wishes to thank *The Villanova Engineer* and its staff for their cooperation in the preparation of this material which is based on an article prepared for their March 1952 issue by William Ambrose, Daniel Grady and Joseph Mino, all of whom graduated as mechanical engineers this past Spring. Our thanks also go to Dean Morehouse and to Professor Auth for clarifying certain engineering details and for their friendly help. Finally to William J. Miller of the Yarnall-Waring Company goes the credit for obtaining the majority of the pictures which illustrate the article.



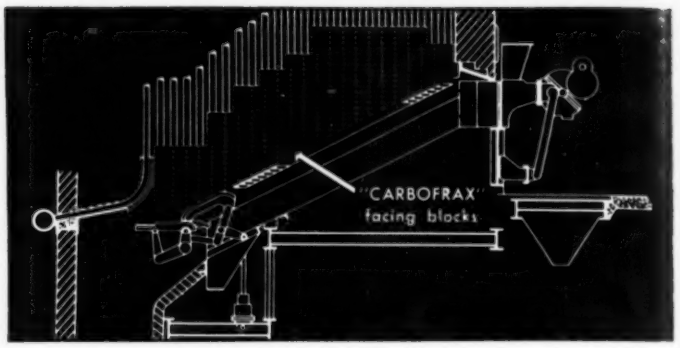
View of boiler feed pumps, one turbine-driven and the other motor-driven; feedwater regulators shown above



Close-up of blowoff valves

TO PREVENT UNNECESSARY SHUTDOWNS...

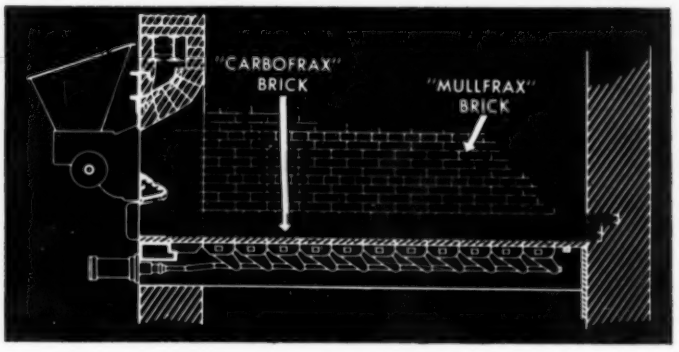
concentrate on the trouble spots!



Multiple Retort Stoker Fired Furnace

CARBOFRAX silicon carbide facing blocks effectively protect tubes and increase their life. They fit the tubes snugly. They will not warp or burn out. Their thermal conductivity approaches that of heat-resisting metals. And these blocks maintain a hot face that helps support combustion when steaming rates fluctuate widely.

In furnace areas that take the brunt of the punishment, to use a refractory that is less-than-the-best is to be penny-wise, pound-foolish. Any avoidable shutdown is so enormously expensive that you just cannot afford to have a "weak link" in your refractory linings. Where the wear and tear is the toughest, it definitely pays to use the best materials you can buy—Super Refractories by CARBORUNDUM. These durable refractories will strengthen all such vulnerable spots—stop trouble before it begins. At the right are two examples.



Spreader Stoker Fired Furnace

CARBOFRAX brick installed above the grates prevent clinker build-up, resist cut-backs caused by high temperatures, and provide a long-lasting, solid foundation. In the front wall, CARBOFRAX piers and arches withstand the unusually severe thermal and mechanical abuse. MULLFRAX electric furnace mullite brick, with their unique resistance to fluid ash, effectively retard erosion of the upper walls. They also remain hard at high temperatures.

Use Super Refractories by

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Engineering Economy in The Electric Utility Industry

By K. M. IRWIN

Vice President, Philadelphia Electric Co.

In these excerpts from a paper presented at the Annual Meeting of the American Society for Engineering Education at Dartmouth College, June 27, 1952, the author outlines typical economic studies that must precede decisions on capacity additions, selection of steam conditions and voltage, and discusses the coordinated operation of generating stations.

ENGINEERING and operating departments of electric utilities are constantly engaged in the study and application of economics. In all designs where efficiency is the consideration, the effect on overall dollar economy must be the main determining factor.

In general, an improvement in the efficiency of a generating station requires increased investment which must be justified by the savings made possible. Whether the savings are sufficient to justify the cost of the improvement is a matter that must be decided in view of a large number of considerations, many of which differ widely from location to location. Fuel costs, for example, vary greatly from one part of the country to another. A rate of return on investment considered to be adequate by one management may be insufficient in another situation where diversification of load or the relation of fixed to equity capital is different. The effects of rate tariffs and particularly of taxes are likely to be at variance between utilities and are known to vary from time to time in all locations.

Due to the long life and comparatively low rate of return on electric utility investment, all economic studies must consider the entire expected life of the equipment. A new plant or piece of equipment, due to its greater economy, may operate at high capacity in the early years of its life, but gradually its economy may be surpassed by new equipment and it will then be run for less hours and at lower loads through the ensuing years. Therefore, the operating savings to be evaluated against the investment must be based on the expected life average rather than the larger savings accruing immediately. However, for short-time, peak-load conditions such equipment as has been displaced in the efficiency rate may have long-continued usefulness.

Careless use of figures can often lead the engineer astray in economic studies. Take the capital cost as one example. All too often in studies, the direct construction cost is used as capital cost, completely ignoring the essential engineering costs and general company overheads. Operating cost can also be misleading. The operating department expense alone does not represent the entire operation cost. Its pro rata share of general company overhead may amount to as much as 25 per cent of the departmental expense, less fuel cost.

The effect of income taxes may be misleading. Assume a study has been made on a 5-per cent return basis and it is desired to see the effect of a 6-per cent return. For 5-per cent return, $2^1/_2$-per cent depreciation and 4.3-per cent taxes, the total fixed charges would be 11.8 per cent. Apparently for 6-per cent return the fixed charges would be 12.8 per cent. However, under present income tax laws, the tax rate increases with the return and would be 5.5 per cent in place of 4.3 per cent, making fixed charges for 6-per cent return 14.0 per cent instead of 12.8 per cent. In other words, a 20-per cent increase in return would have an accompanying 28-per cent increase in taxes. These figures are purposely simplified and do not include state revenue taxes, etc.

Another mistake sometimes made is the wrong interpretation of what might appear to be incremental figures but which are not incremental. Assume a present-day statement of total revenue R_1, total expense E_1 and total units of output U_1, and an estimate of the same figures at a time ten years hence as R_2, E_2 and U_2. If the same rates of revenue, labor, fuel and other costs were used in both sets of figures, then $R_2 - R_1$ divided by $U_2 - U_1$ would give the incremental revenue for the additional units of output, and $E_2 - E_1$ divided by $U_2 - U_1$ would give the incremental expense for the additional units. However, if there were changes in rates of revenue, labor, fuel, etc., the division of $R_2 - R_1$ or $E_2 - E_1$ by $U_2 - U_1$ would not give an incremental rate for the additional units since both R_2 and E_2 would reflect the increases or decreases of all of the U_1 units. The effect would be to charge the new units $U_2 - U_1$ with their own increment plus or minus the changes for all of the U_1 units.

Scheduling Construction of Steam Generating Stations

When it is decided to add a turbine-generator there is usually more than one location at which it is possible to make the installation and all locations may have attractive features in different combinations. In a recent study by the Philadelphia Electric Company, three sites on the System appeared to be interesting. Each fulfilled the requirements of adequate circulating water, coal delivery facilities and of being located in

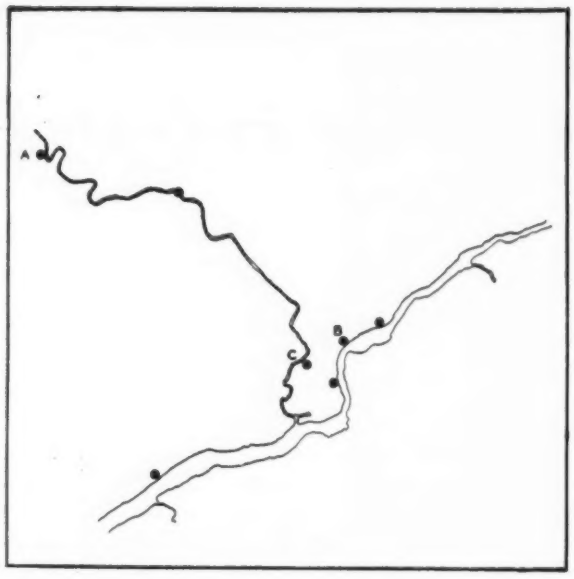


Fig. 1—Map of plant locations in Philadelphia

areas requiring capacity reinforcement. Fig. 1 is a sketch of the Philadelphia area with dots along the rivers showing the approximate locations of generating stations. Locations *A*, *B* and *C* were available for new units, and all eventually will be utilized. The immediate problem was to determine the preferable sequence.

Location *A* was a new site adjacent to a large substation and convenient to rail coal. Foundation conditions, as demonstrated by core borings were almost ideal. A very minimum of river work would be required. Location *B* was a property, adjacent to an existing generating station, which, for more than a century, had been used as a shipway. It was felt that foundation work at this location would be expensive, due to the subsurface obstacles that were sure to be present. Several hundred feet of bulkhead would be required and it was estimated that the preparation of the site would cost several million dollars more than at Location *A*. At Location *C* the opportunity was presented to install one unit in an existing building by the removal of some very old capacity. No addition would be required to coal-handling facilities and very minor modifications would be required for handling circulating water. Preliminary studies indicated that the transmission requirements for the installation of two turbine-generators of 125,000 kw capacity would be substantially the same, regardless of whether both were at Location *B*, or one each at Locations *A* and *C*.

As shown by Fig. 2, a number of sequences were chosen to determine the order in which these units should be installed. These are not nearly the total number of sequences that could have been chosen nor do they include all the sequences that were examined. However, for the representative choices, it does show the estimate of the differences in the net cumulative annual costs for the five-year period during which it is expected these four units will be installed. The net cumulative annual costs represent for each sequence the additional costs of capital and operating labor less the operating savings due to different unit loadings and transmission losses. It is quite obvious that sequence No 5 was substantially less expensive and, therefore, much more attractive. As would be expected, it was decided at that time to begin with the installation of two units at site B.

CONDITIONS APPLICABLE TO CASES

CASE	STEAM PRESS.	STEAM TEMP.	REHEAT TEMP.	BLR. FD. TEMP.	STACK TEMP.
A	850	900	—	350	400
B	850	900	—	350	300
C	1250	950	—	425	300
D	1450	1000	—	450	275
E	1450	1000	1000	450	275
F	1800	1000	1000	450	275
G	2000	1050	1050	500	275

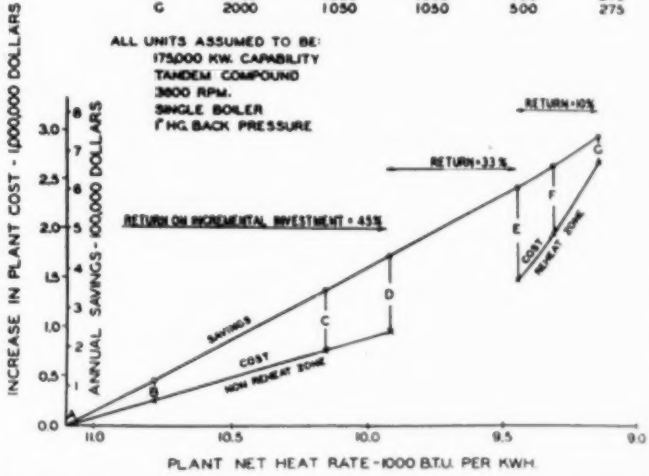


Fig. 3—Economic comparison among generating stations of various efficiencies

	SEQUENCE NO. 1	SEQUENCE NO. 2	SEQUENCE NO. 3	SEQUENCE NO. 4	SEQUENCE NO. 5
1ST. UNIT	*1 SITE B	SITE A	SITE A	*1 SITE B	*1 SITE B
2ND. UNIT	SITE A	*1 SITE B	SITE C	SITE C	*2 SITE B
3RD UNIT	SITE C	SITE C	*1 SITE B	SITE A	SITE A
4TH UNIT	*2 SITE B	*2 SITE B	*2 SITE B	*2 SITE B	SITE C
DIFFERENTIAL COST	BASE	-$100,000	-$1,000,000	-$800,000	-$5,100,000

Fig. 2—Sequences chosen to determine order of installation

Selection of Steam Conditions

The choice of steam conditions for a fuel-burning plant (pressure, temperature and reheat) is a subject for careful, extensive economic studies. Fig. 3 presents graphically the results of a study made on this subject. Highly technical considerations, operating requirements

and considerable judgment all had a place in the study.

Seven different steam conditions were investigated. In each case the effect on capital costs and on operating savings was developed and referred to the lowest priced and least efficient set of steam conditions as a base.

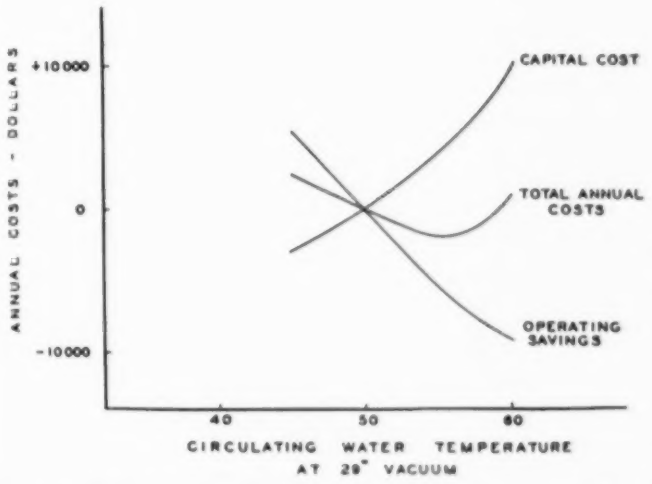


Fig. 4—Optimum circulating water temperature for Delaware station

It will be noted that as the net heat rate is improved, the cost of the installation is increased. This increase is fairly gradual in the non-reheat zone and the increment involved in the application of reheat is not excessive. However, the curve becomes steeper with reheat. The operating savings are shown to be almost directly proportional to the improvement (decrease) in net heat rate. However, excluding the effects of taxes, coal clause adjustment, etc., the gross return on the increment investment required to improve the heat rate in the non-reheat zone (from Case A to Case D) is about 45 per cent. A gross return of about 33 per cent may be expected from the first step of reheat. But the return to be made through advancing the steam conditions in the reheat zone from Case E to Case G is only about 10 per cent on the increment investment. This clearly shows that, at least within the limits of this study, as the designs reach further and further to the regions of higher efficiency under the present steam cycle, there is a definite trend toward reduced returns.

Selection of Steam Condensers

One more strictly economic comparison may be of interest. Fig. 4 shows the results of a study which was prepared to aid in the selection of the optimum cooling surface for steam condensers. In this case the condensers were specified on the basis of having surface adequate to produce 1 in. of mercury back pressure with a specified circulating water temperature. Obviously, if the specified temperature were increased, more surface would be required.

The curve marked "Capital Cost" represents the increasing cost of money required to buy a condenser of a size that would produce the desired vacuum with the circulating-water temperatures as indicated, using 50-F water as a base. The improvement in average vacuum which the greater surface would develop through the year results in more efficient operation. The curve marked "Operating Savings" shows the savings in operating expense with increase in the size of the condenser, again using 50 F as base. Adding these two curves together results in the curve marked "Total Annual Cost," which may be seen to have a minimum at a point corresponding to about 55 F. It was therefore, decided to specify the condenser on the basis of developing 1-inch mercury back pressure at 55 F circulating water temperature.

Coordinated Operation of Generating Stations on the System

Use of incremental costs plays a large part in the economical operation of individual generating systems and of interconnected systems. Large sums are at stake, involving 75 generating units of 30,000 kw or larger in the interconnected systems with which I am most familiar. Outage of one of the latest, most efficient steam units may involve fuel costs of $11,000 per day. Fig. 5 shows the relation of coal input to kilowatt output of our Chester Station, when operating only the pulverized-fuel boiler. The degree of slope of these curves represents the incremental increase in fuel consumption for incremental increases in load. Fig. 6 illustrates the incremental coal rates as taken from the curves of Fig. 5 and indicates in the table at the bottom how fuel increment plus maintenance increment give

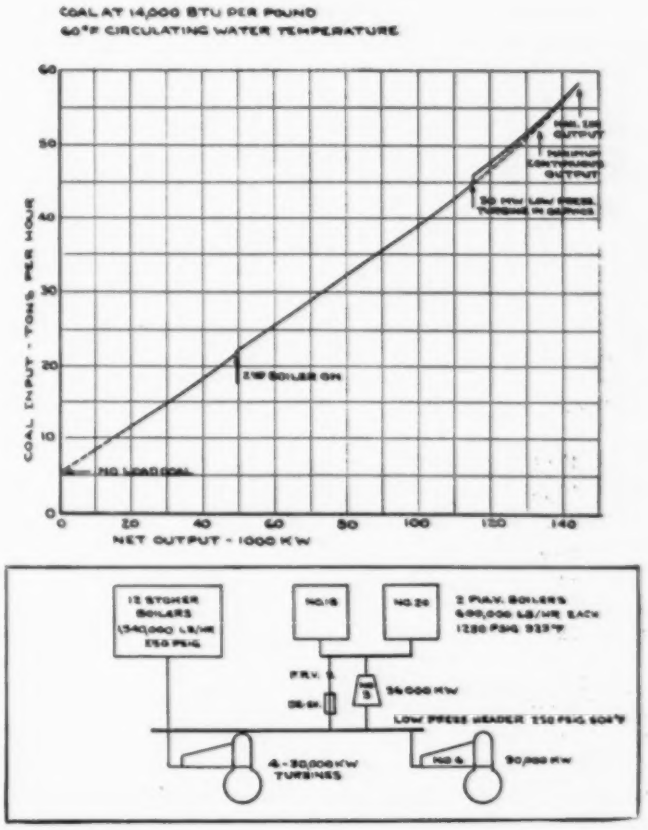


Fig. 5—Coal input vs. net station output for the Chester generating station

the increment production cost. Such data are available for all Philadelphia Electric Company stations as well as for all stations of the F.P.C. Area No. 5 interconnection.

Selection of Voltage for a Transmission Line

In connection with a new generating station there will be required a relatively high capacity transmission connection to deliver power into the high voltage transmission network of the Philadelphia Electric Company. A study was made for the transmission voltages of 66, 132 and 220 kv, under load conditions forecast for an ultimate installation of 350,000 kw in the new station. It was found that the 132-kv plan would result in minimum capital investment and also provide improved operating flexibility with respect to other high-voltage portions of the system.

The cost estimates indicate relative capital expenditure for the three voltages to be as follows:

66 kv	$ 9,149,000
132 kv	$ 8,305,000
220 kv	$10,378,000

The facilities required under the various voltage plans are considerably different as to line routes, terminals and terminal facilities but are of a nature to accomplish approximately the same overall result in each case.

Capacitors for Primary Circuits

A study also was made of the economic advantages of increasing the capacity of our existing distribution circuits through the installation of shunt capacitors. It was determined that the capacitors would provide a low cost alternative to conventional substation and circuit capacity additions to accommodate load growth. The capacitors would provide an immediate and continuing cash benefit due to the saving in system losses by neutralizing inductive kva directly in the load area.

An analysis of the operating economy through reduction of system losses at current increment capital costs would be sufficient to net a 50-per cent return on a $177,000 investment for 26,600 kva of capacitors, after accounting for the fuel clause adjustment and income taxes.

The economic analysis included the following factors:

1. Reduction of system losses
2. Non-operation of generating capacity otherwise required for reactive kva supply
3. Investment for capacitors
4. Net return on investment

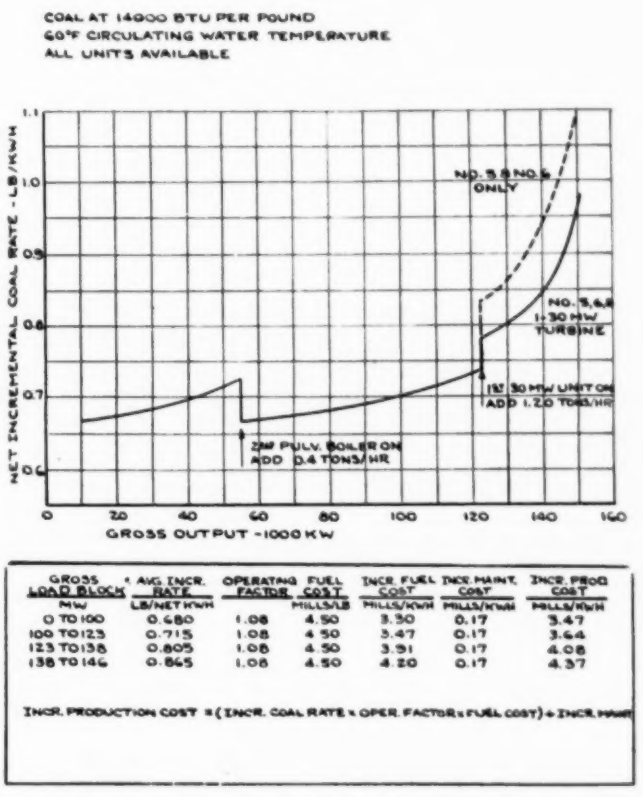
Engineering Economy Possibilities in Electric Generation

Engineering economy points out that the major part of future electric load must be supplied by fuel (combustion or atomic) generation. Water power sites have been developed to a considerable extent. Although there are undeveloped sites still available the high cost of construction involved tends to counteract the comparatively low operating costs. Many of the hydro-electric sites are only adaptable for run-of-the river plants. Such plants must be integrated with large steam systems in order to have full capacity value during low flow periods. Without this capacity value, the capital charges would overbalance the operating savings. Comparatively few remaining sites for large hydro-electric developments are adjacent to large systems and, of these, many are of a character requiring an exceptionally high capital investment.

With steam generation, possibilities now in view include reducing the temperature of gases leaving the stacks, double reheating of the steam passing through the turbine, reduction in the amount of spare equipment for auxiliary service, and reduction in the extent of building enclosure for major equipment. Some reduction in unit capital cost will be realized through the use of still larger turbine-generators and boilers. It is now expected that capacities up to 250,000 or 300,000 kw will be available soon.

Eventually nuclear reactors may come into practical use for steam generation, but in the utility industry, engineering economy requires that the total cost of the fuel and plant be reduced to the point where it is competitive with that for conventional boilers as well as other fuels.

The more immediate practical possibilities of the gas turbine are receiving considerable attention. It requires no boiler house, and only moderate quantities of cooling water; hence, can be installed in relatively small units near the loads. The gas turbine holds promise of decreasing the need for costly construction associated with the provision of extremely large boilers, condensers and cooling water facilities, together with expensive buses, circuit-breakers and transmission plant associated with the use of massive steam turbine-generator plants. Here evaluation will require most careful engineering economy analysis.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NO. 5 & 6 + 30 MW TURBINE
1ST 30 MW UNIT ON ADD 1.20 TONS/HR
2ND PULV. BOILER ON ADD 0.4 TONS/HR

GROSS LOAD BLOCK MW	AVG. INCR. RATE LB/NET KWH	OPERATING FACTOR	FUEL COST MILLS/LB	INCR. FUEL COST MILLS/KWH	INCR. MAINT. COST MILLS/KWH	INCR. PROD COST MILLS/KWH
0 TO 100	0.680	1.08	4.50	3.30	0.17	3.47
100 TO 123	0.715	1.08	4.50	3.47	0.17	3.64
123 TO 138	0.805	1.08	4.50	3.91	0.17	4.08
138 TO 146	0.865	1.08	4.50	4.20	0.17	4.37

INCR. PRODUCTION COST = (INCR. COAL RATE × OPER. FACTOR × FUEL COST) + INCR. MAINT.

Fig. 6—Net incremental coal rate at the Chester generating station

Improved Utilization of Waste Heat*

By ING. DR. RICHARD DOLEZAL
Vitkovice Steelworks, Ostrava, Czechoslovakia

Utilization of waste heat in a fire-tube boiler operating with internal-combustion engine exhaust was increased by insertion of thin-walled tubes within the existing tubes, thus gaining the benefit of radiated heat. Output and efficiency were increased and the pressure brought up to that for which the unit was designed.

A SCHEMATIC cross-section of the reconstructed boiler installed in a Czechoslovakian plant, is shown in Fig. 1. The boiler, with a heating surface of 2100 sq ft, was designed to operate at 178 psi pressure and approximately 600 F steam temperature. After installation it was found that the economizer was too large and the temperature of the feedwater following the economizer was nearly as high as that of the saturated steam. This resulted in occasional steaming in the economizer, especially when the feeding was irregular. The heat transfer of the convection heating surfaces of the boiler proved to be less than the value assumed by the designers; hence, the steam output and pressure were lower than had been anticipated.

Changes were indicated in order to reduce the feed temperature and increase the heat absorption in the boiler. It was not considered advisable to reduce the

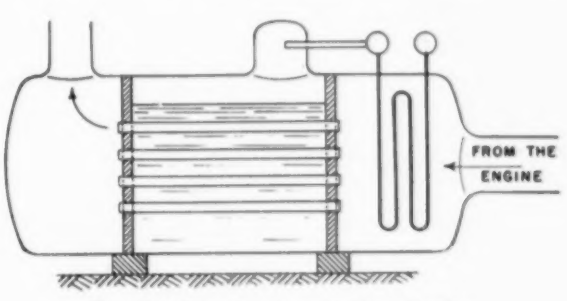

Fig. 1.—Sketch of waste-heat boiler

economizer surface since this would have led to further reduction of the steam output and boiler efficiency. Therefore, it was decided to increase the coefficient of heat transfer of the boiler heating surface by the following means:

A cross-section of a tube, as originally installed, is represented by Fig. 2. The heat transfer through the wall is mainly by convection, as the mean temperature of the exhaust gases is too low and the cross-section of the gas stream is too small to produce an appreciable heat transfer by radiation. The temperature gradient across the stream of the exhaust gases, the tube wall, and the water, is indicated in the lower part of Fig. 2.

To increase the heat transfer through the tube, a thin-walled tube of smaller diameter, open at each end, was inserted as in Fig. 3. This was centered by means of three short rods welded to the inserted tube. As these distance pieces are not joined to the outer tube, the whole insert can be removed if necessary.

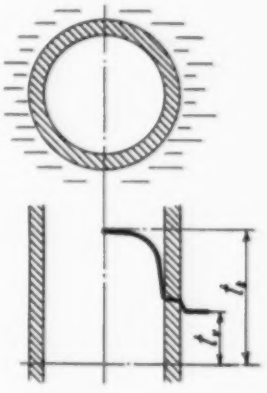

Fig. 2.—Temperature gradient of original tube

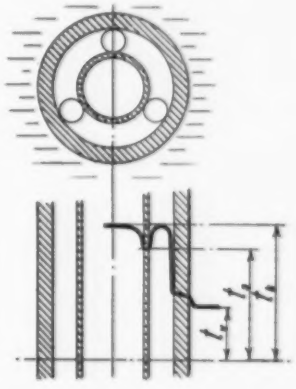

Fig. 3.—Temperature gradient with inserted tube

After the tube had been inserted, the gas streamed through the inside of the inserted tube and also through the annular space between it and the outer tube. As a result, the temperature of the inserted tube increased to the value t_s which, although lower than the temperature of the gases t_k, was higher than that of the outer tube t_e. Since the temperature of the inserted tube is lower than the mean temperature of the gas stream, the gas gives up a certain part of its heat to the inside and outside surfaces of the inserted tube which is considerably hotter than the outside tube, the latter being cooled by the water surrounding it. The hotter inside tube transfers a part of its heat to the external tube by radiation. Only the outside surface of the inserted tube participates in this useful heat radiation, and the transfer of heat from the inside of the inserted tube to its outside takes place by conduction. For this reason it was necessary to reduce the wall thickness of this tube to a minimum and to use a material with a good heat conductivity, i.e., mild steel.

Insertion of the thin-walled tube caused only a negligible increase of the gas velocity but the hydraulic radius of the gas stream in the tube was considerably reduced,

* Translated by E. Gros, London, England.

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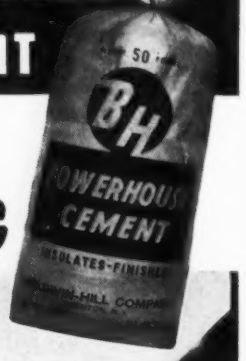

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which brought about an increased heat transfer by convection from the gases to both tubes. Since the withstanding of pressure was not involved, cheap reject tubes were used for the inside.

The pressure loss of the exhaust gases was increased only very slightly after inserting the inner tubes as a result of turbulence at the tube entry and exit points. Owing to the reduced hydraulic radius of the gas stream the pressure losses due to friction of the gases along the tube surfaces increased, but these losses are small compared to those due to turbulence at the entry and exit of the individual tubes; thus, the total pressure loss increased only slightly.

Test Results

Performance of this boiler was measured before the tubes were fitted and six months later. The readings taken prior to fitting the insert tubes were made directly after cleaning the economizer, but the values obtained six months later were affected by a scale layer which had deposited in the meantime, since hard, unconditioned feedwater had been used. The values obtained without and with the insert tubes are given in the table.

From this it will be seen that after fitting the insert tubes the steam output increased and the feedwater temperature decreased. Calculations showed the absorption rate to have increased from 2175 to 2396 Btu per sq ft per hr. This increase appears to have been due to the heat radiated by the inserted tube, as well as to increased convection due to the reduced hydraulic radius of the exhaust gas stream. Both these factors contributed its share to the increase of heat transfer.

The insert tubes proved fully successful and the water temperature leaving the economizer dropped from 330 to 291 F, while the steam output increased approximately 5 per cent. The steam pressure increased to the desired value despite the fact that the water supplied by

TEST RESULTS

	Values Obtained Before Fitting the Insert Tubes	Values Obtained After Fitting the Insert Tubes
Steam output, lb per hr	5,331	5,600
Steam pressure, psig	143.6	178
Feedwater entering economizer, F	144	154
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Exhaust gas temperature at entry to boiler tubes, F	960	959
Exhaust gas temperature at exit from boiler tubes, F	548	507
Water temperature in boiler, F	365	378
Quantity of utilized exhaust gases (calculated values) cu ft per hr	610,863	596,739

the economizer was cooler. The gas input after fitting the insert tubes decreased by about 2 per cent, and the inflow velocity remained practically unchanged. The overall efficiency of the installation was improved by 7.1 per cent, which presumably would have been greater if treated water had been used.

The insert tubes were fitted into the boiler tubes in April 1948 and no trouble whatever was experienced with the exhaust gas stream as a result of the effected modification. After fourteen months' continuous operation an examination showed the surfaces of the flue gas tubes and the insert tubes were clean and free of dust deposits.

Savings Obtained

This installation is in operation 6500 hr per year, and as a result of fitting the insert tubes, the steam generation increased a total of 1,716,000 lb during this period.

Handling of Giant Stator

Two years of transportation planning were climaxed last month with delivery of a giant General Electric 200-ton stator for one of the 175,000-kw generators in Consolidated Edison's East River Station in New York.

Taxing transportation facilities en route from the G-E turbine manufacturing center at Schenectady, the huge stator was moved by rail, water and heavily reinforced trailer to the power house at Fourteenth Street and East River Drive. Two railroads, a specially-built flat car, one of the world's largest floating derricks, a lighter (special barge), two tugboats and a Manhattan firm of heavy hauling specialists were needed to move this giant 30-ft long component.

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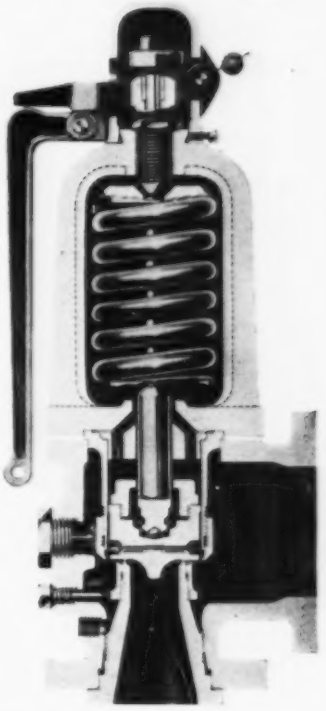

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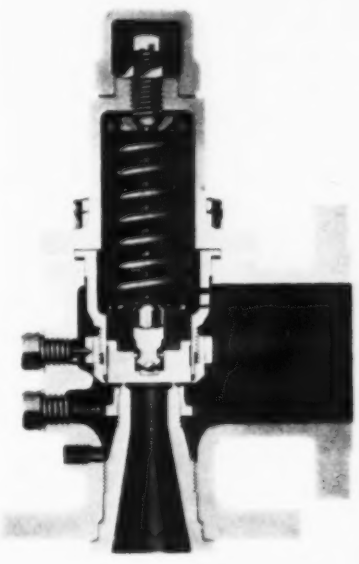

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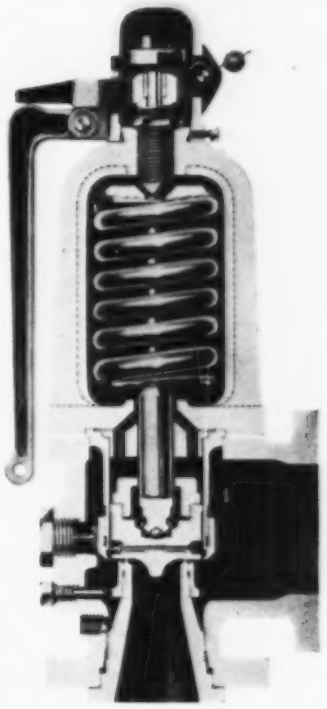

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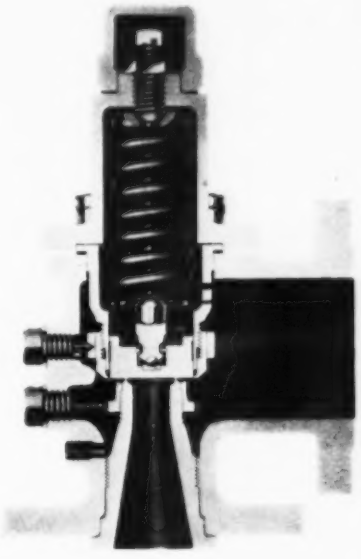

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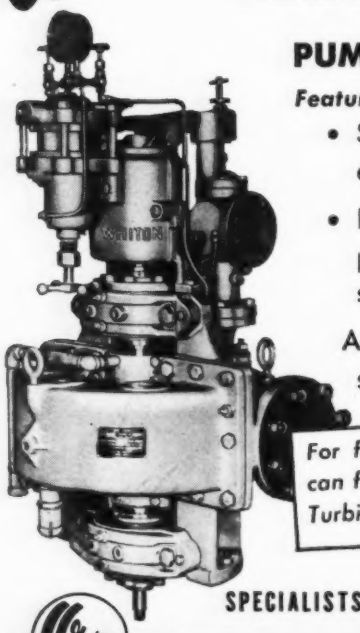

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- SOLID STEEL ROTOR . . . gives high efficiency for low-speed, direct drive.
- LABYRINTH SHAFT SEAL . . . positively prevents leakage. Eliminates wear and seizing.

Available in various types and frame sizes up to 600 Horsepower.

For full information on how Whiton Turbines can fill your requirements, write directly to our Turbine Division.

SPECIALISTS IN HORIZONTAL AND VERTICAL TURBINES.

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WHITON MACHINE CO.

NEW LONDON 14, CONN., U.S.A.

NOW...1 MAN *Stores Coal Faster...*

Small Sauerman Scraper above is shifted radially by moving its tail-block along a bridle cable. Large installation at left uses remotely controlled tail tower to provide automatic shifting.

with a SAUERMAN POWER SCRAPER

Speed up coal storage the easy, efficient way—with a "one-man" Sauerman Power Drag Scraper. Any tonnage can be handled readily with maximum utilization of any sized area. The operator needs little training . . . his job is easy and working conditions are comfortable.

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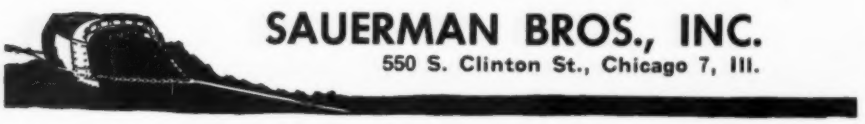
Write today for the Sauerman Coal Storage Catalog



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550 S. Clinton St., Chicago 7, Ill.

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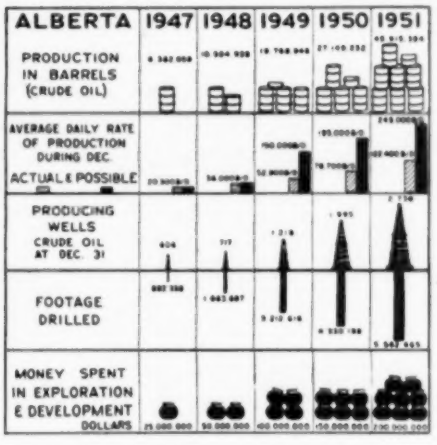

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high efficiency AEROTEC

DUST COLLECTORS

Partially erected collector showing inlet, outlet and dust discharge passages.

New Niagara-Mohawk Power Corporation Dunkirk Steam Station, equipped with Aerotec Dust Collectors.

assure your plant the same protection given the new

NIAGARA MOHAWK POWER CORPORATION

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Write for the new Design 3 RAS Catalog No. 601.

Project and Sales Engineers

THE THERMIX CORPORATION

GREENWICH, CONNECTICUT

(Offices in 38 Principal Cities)

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THE AEROTEC CORPORATION

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Manufacturers of mechanical dust collectors, electrical precipitators, air cleaners, industrial integral dust collectors, gas-oil scrubbers and dust reclaiming equipment.

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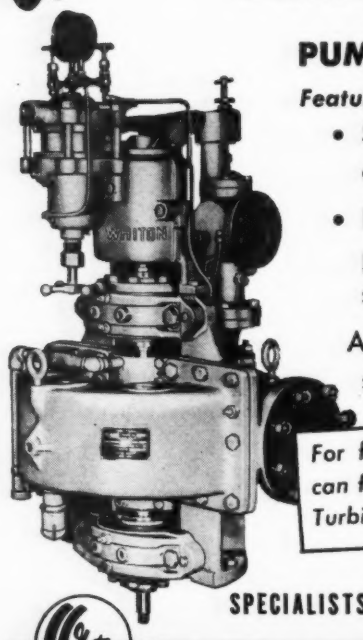
SOLID STEEL ROTOR

VERTICAL TURBINES

Economical—Dependable . . . for

PUMPS • FANS • COMPRESSORS



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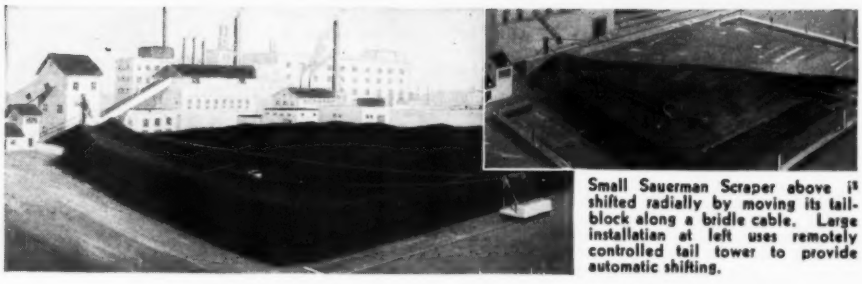

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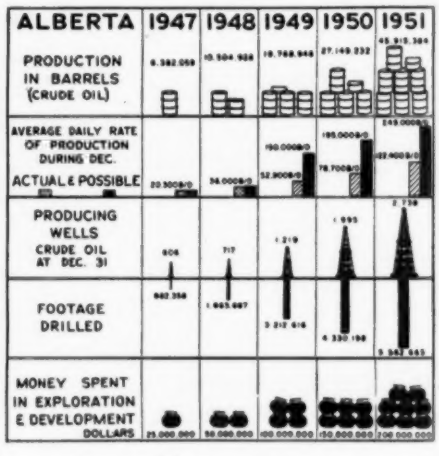

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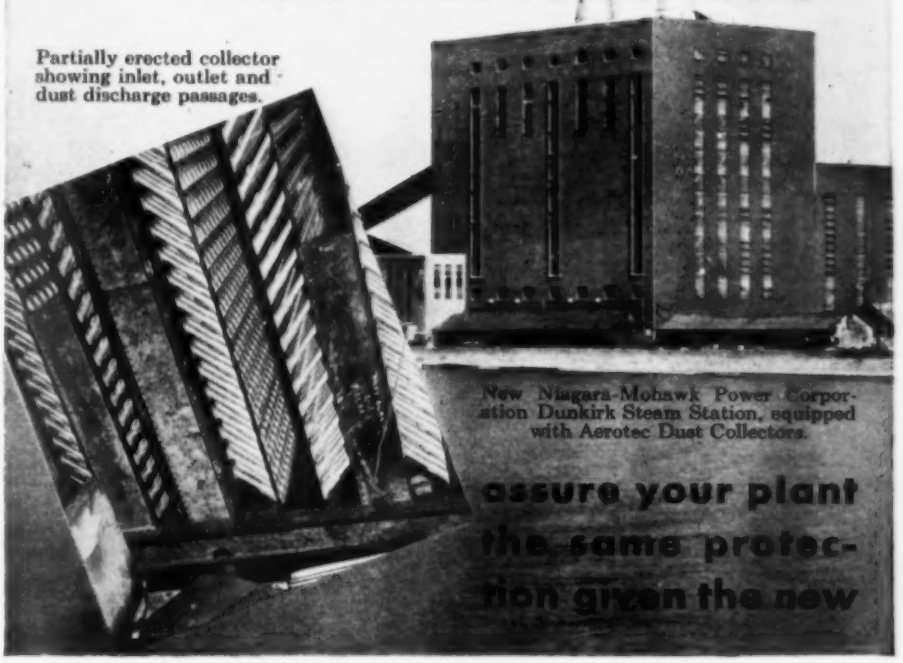

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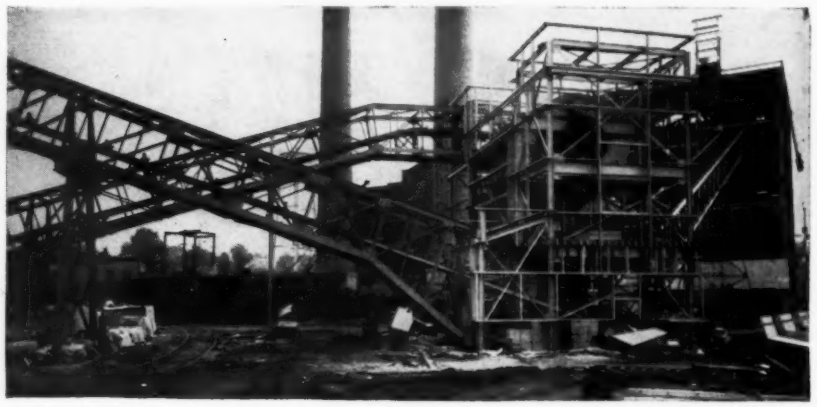


A coal handling installation under construction at Lorain, Ohio.

Low Cost Coal Handling

When coal is to be handled in large quantities, equipment must be planned with three factors in mind:

(1) Efficiency
(2) Moderate installation and operating cost
(3) Low maintenance costs

Careful design for the particular job is the answer

From estimate to completed installation, Sy-Co Corporation treats your materials-handling problem with the skill that comes only from experience.

Sy-Co CORP.

Sy-Co Corporation
Conveying Systems for Every Purpose
125 Broad Street **New York 6, N. Y.**

o Wednesday morning, October 2
The shipyard tour will embrace a tri through the structural shop witnessin the fabrication of ship assemblies o steel and of aluminum. The Air Materiel Center tour will consist of observing forming, fitting and joinin practices, viewing of a catapult shoot ing a dead test load, a demonstration o pilotless helicopter, a trip through the paint shop, a demonstration of the ejec tion seat and a fire fighting show.

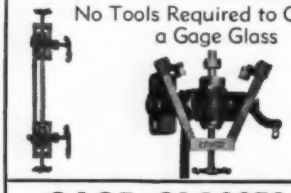
The other major tour on Wednesday morning will be to the Steam Division of the Westinghouse Electric Corporation at Lester, Pa. This will show the latest methods and materials used in producing steam turbines for central power stations. The latest fabrication techniques of low alloy steels, submerged arc welding and low frequency induction heating equipment for stress relieving and preheating weldments will be displayed. Many types of heat-exchanger equipment and production machines will also be shown.

All tours will be restricted and visitors must comply with Navy regulations.

An outstanding event will be the Annual Dinner on Thursday evening during which the annual honor awards will be presented by Charles H. Jennings, president of the Society.

ERNST SPLIT-GLAND GAGE

No Tools Required to Change a Gage Glass



Made to fit any water column tank or boiler in bronze construction or forged steel. For pressures 250 lbs. up to 900 lbs. with screwed or flanged connections, specify your gage centers and connections required.

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GAGE GLASSES AND
High Pressure Rubber Gaskets
ALL SIZES TO FIT YOUR WATER GAGES

ERNST WATER COLUMN & GAGE CO.
Send for Catalog **LIVINGSTON, N. J.**

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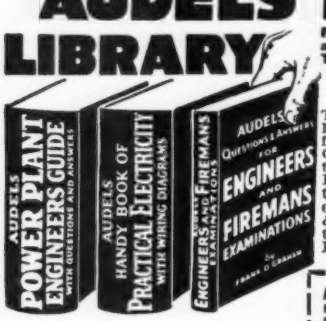

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Oxygen, one very active source of destructive boiler corrosion, is continuously detected and recorded by the Cambridge Gas Analyzer. The oxygen dissolved in the feed water is determined directly, and continuously recorded upon the Cambridge Dissolved Oxygen Recorder. The oxygen set free by dissociation in the boiler is determined by measuring the free hydrogen in the steam which is recorded upon the Cambridge Dissolved Hydrogen Recorder. Cambridge Analyzers are available in models for continuously recording either O_2 or H_2 separately or O_2 and H_2 simultaneously.

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DISSOLVED O_2 & H_2
ANALYZERS

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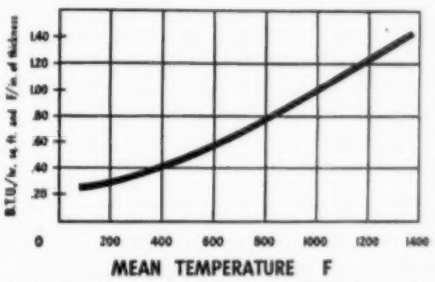
New Ceramic Fiber Resists High Temperatures

A new synthetic ceramic fiber, trademarked "Fiberfrax," which possesses very high heat resistance and unusual electrical properties, has been announced by The Carborundum Co. It is claimed to retain its properties at 2300 F and that it will not soften at temperatures approaching 3000 F.

Made by melting aluminum oxide and silica in an electric furnace, then subjecting a stream of the molten material to a blast of air, the product



Thermal conductivity of Fiberfrax at 6 lb per cu ft density.

becomes a fluffy, white, cotton-like mass of extremely fine fibers having an average diameter of about one-twenty-fifth that of a human hair. As blown, the material weighs about two pounds per cubic foot. It may eventually be processed into felted blankets, firmly bonded batts, tape or paper-like forms.

In addition to use for high-temperature insulation, the fineness, resilience and random arrangement of fibers suggest the following potential applications: as a super-filter for gases and liq-

Two pounds of Fiberfrax (center), packed to 6 lb per cu ft density, fill the same volume as 14.6 lb of high-grade refractory insulating brick and furnish the same insulating efficiency as 20.9 lb of the latter.

uids in chemical operations; as packing for expansion joints; vibration dampening; electrical insulation; replacement of or use in combination with critical asbestos for certain uses; insulating panels; and fire protection. Reported insulation tests indicate savings in weight and efficiency when compared with high-quality insulating brick as used in industrial furnaces.

STOP YOUR HEAT LOSSES

with the Truly Better—More Economical Plastic Insulation

IT STICKS
IT INSULATES
IT'S EASY TO APPLY

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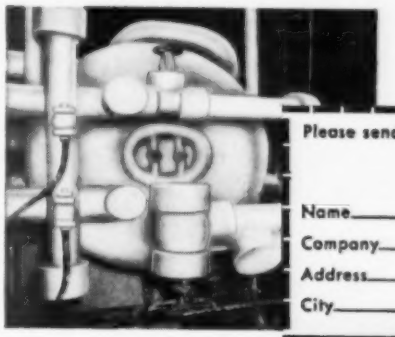
Boiler Walls
Breechings • Drum Heads
Elbows • Flanges
Fittings • Valves
Feed Water Heaters
Ducts, Lines & Piping
Dust Collectors
Gas Generators
Kettles • Tanks
Steam Heaters
Steam Pumps
Air Heaters & Preheaters

More than 50 million pounds of Stic-Tite in service on the power generating and process heating equipment of American industry—over many years—prove Stic-Tite incomparable for ease of application, strength, insulating efficiency and long-run economy. It's truly the ideal plastic insulation on metal or on block or blanket insulating surfaces for temperatures to 1800° F. Try this all-purpose insulation. Your own tests will convince you.

- *More Adhesive*
- *Stronger—More Durable*
- *More Resistant to Air Infiltration*
- *Easy to Apply and Finish Smooth*
- *More Efficient*
- *Economical Coverage*
- *Indestructible—Completely Reclaimable*



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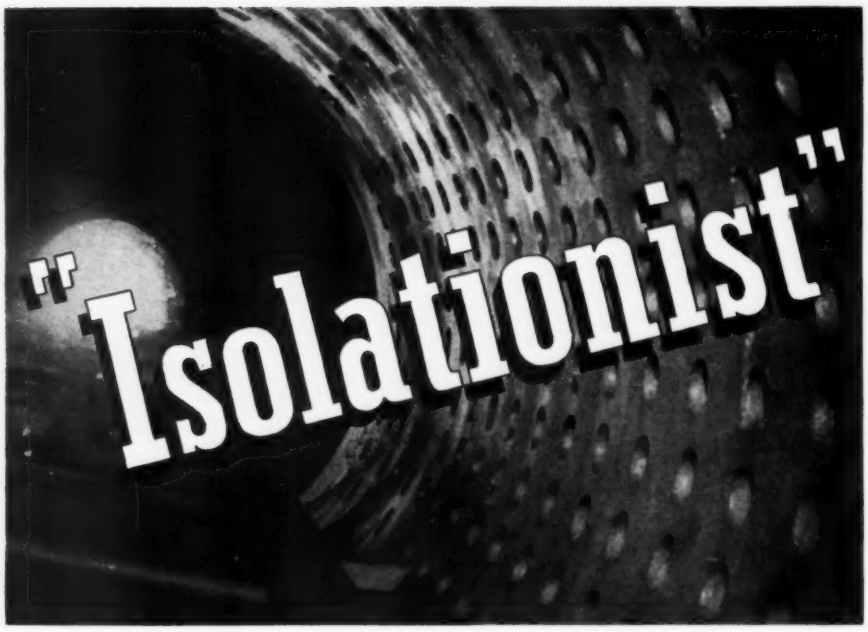

When it comes to steam generating policy, here's a label *any* boiler wears with pride, for there's no disputing the merits of isolation for tube and drum steel. Not one world but two is the ideal to be attained when metal must live with water. Because the one always will remain potentially destructive of the other, the nearest approach to total security for boiler steel is the erection of a defense against even good boiler water. Making such a defense practicable is the function of APEXIOR NUMBER 1 protective surfacing.

To clean boiler steel either new or previously in service APEXIOR adds a brush-applied barrier insoluble in all waters . . . unaffected by steam at any temperature or pressure . . . inert so that it cannot bond chemically with operating deposits which are, in fact, repelled by APEXIOR's smooth surface. That's why after months or even years of operation APEXIORized boilers come off the line untouched by corrosion—so clean a minimum of surface maintenance sends them back into service for continuing highest-efficiency performance.

APEXIOR NUMBER 1 separation of steel from water is a theory and practice backed by thirty-five years' industrial, central station, government, marine and railroad use in boilers of every size and design—is universally specified by consulting engineers, endorsed by manufacturers, and recommended by boiler insurance companies.

APEXIOR NUMBER 1 is a product of Dampney Maintenance for Metal — equipment-engineered coatings formulated to meet such specific power and processing needs as internal boiler protection. For all of your difficult or unusual corrosion control requirements — whether involving diesel engines or fume-carrying ducts . . . steam turbines or corrosive-handling tanks . . . be right—and right the first time—by specifying Dampney.

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THE DAMPNEY COMPANY

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Annual Water Conference Program

The Thirteenth Annual Water Conference sponsored by the Engineers' Society of Western Pennsylvania will be held at the Hotel William Penn, Pittsburgh, October 20 through 22. Papers and discussions scheduled for the program are as follows:

Monday morning, October 20

"Experiences With Chloride Anion Exchangers for Reducing Alkalinity Without Acid" by S. B. Applebaum, Cochrane Corp., Philadelphia, Pa.

Monday afternoon, October 20

"Experiences With Application of Deaerating Heaters to Industrial and Utility Feedwater Cycles" by V. J. Calise, Graver Water Conditioning Co., New York, N. Y.

"Deionization Vs. Evaporation of Hard Water Supplies for Boiler Make-Up" by T. C. Hoppe and R. A. Russell, Black & Veatch, Kansas City, Mo.

Tuesday morning, October 21

"Report of Activities of Joint Research Committee on Boiler Feedwater Studies" by P. B. Place, Joint Research Committee, Combustion Engineering-Superheater, Inc., Chattanooga, Tenn.

"Advances in Process and Cooling Water Treatment" by A. E. Griffin, Wallace & Tiernan Co., Inc., Newark, N. J.

"Application of Metallic Phosphates to Cooling Water Treatment" by William J. Stone, Deady Chemical Co., Kansas City, Mo.

Tuesday afternoon, October 21

"The Effect of Circulating Water on Wood in Cooling Towers" by J. S. Hill of Esso Standard Oil Co., Baton Rouge, La.

"Bacteria Growths and Their Control" by R. S. Wise, National Aluminate Corp., Chicago, Ill.

"Depositions and Their Control in Cooling Tower Waters" by George Illig, Hall Laboratories, Pittsburgh, Pa.

"Corrosion and Its Control" by J. F. Wilkes, Dearborn Chemical Co., Chicago, Ill.

"A Review of Testing Techniques in Cooling Tower Waters" by J. K. Rice, Cyrus William Rice Co., Pittsburgh, Pa.

Wednesday morning, October 22

"Effect of Operating Pressure on Carbon Dioxide Content of Steam" by J. J. Maguire and R. E. Winston, W. H. and L. D. Betz, Philadelphia, Pa.

"Control of Resinous Materials in Low Pressure Boilers" by W. L. Andrews, The Bird-Archer Co., Limited, Cobourg, Ont.

New Catalogs and Bulletins

Any of these may be secured by writing Combustion Publishing Company, 200 Madison Avenue, New York, 16, N. Y.

Flexible Coupling

A four-page bulletin describes the De Laval Crown coupling, which is of the flexible type. Complete information is provided on construction, horsepower ratings, speeds, applications and selection.

Ash-Handling Systems

Catalog No. 652 is an eight-page bulletin on pneumatic ash- and dust-handling systems prepared by the Allen-Sherman-Hoff Co. A center spread provides an impressive schematic diagram of a pneumatic system for handling both furnace bottom and fly ash. In addition to a description of system components the bulletin contains information on ash hoppers, grids and clinker grinders, transport pipe and fittings, cyclone-collector equipment, storage silos and unloading equipment.

Supervisory Instruments

Brown Instruments Division of Minneapolis-Honeywell Regulator Co. has made available catalog No. 90-2, "Supervisory Instruments for Power Generation," which consists of 41 pages devoted to the instrumentation involved in power generating stations. The measurement of temperature, pressure, flow, power generation and other variables are discussed.

pH Meter

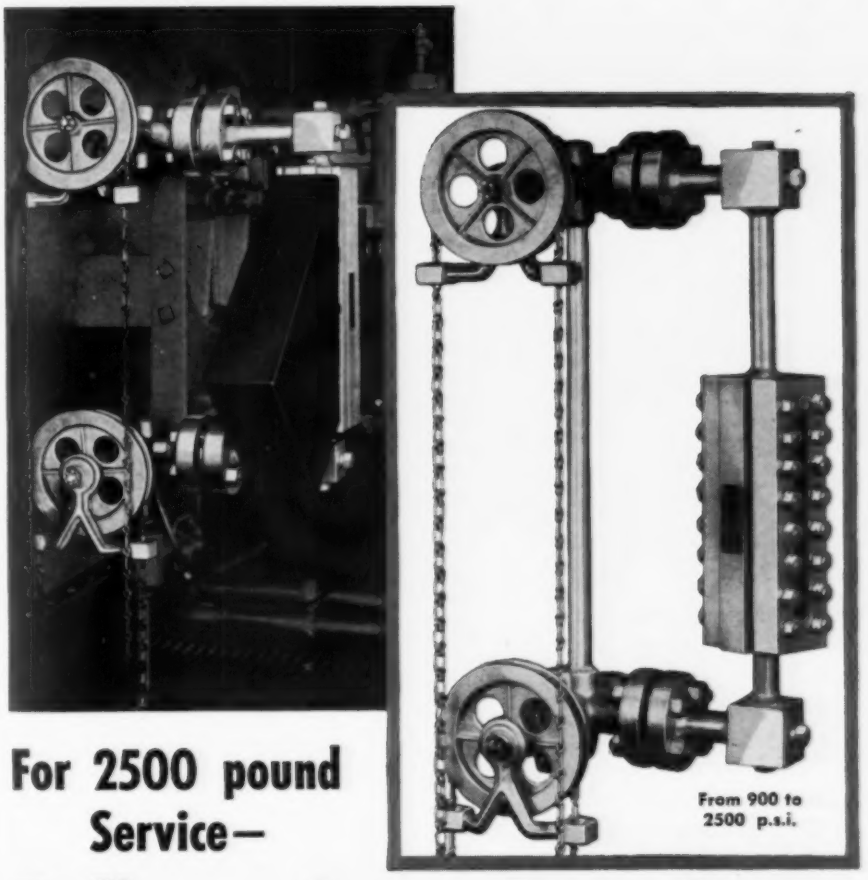
Bulletin No. 326 prepared by the Burrell Corp. describes a compact pH meter for measurements of aqueous solutions. Features of design and convenience of operation are explained.

Pressure-Type Filter

Graver Water Conditioning Co. has published a 12-page bulletin describing the details of design and construction of pressure-type filters for the removal of visible suspended matter from water. Many illustrations of installations are included, together with complete tables of capacities, dimensions and weights for both horizontal and vertical filters.

Crusher Selection

A fascinating and extremely well written 12-page bulletin on crusher selection has been prepared by the Pennsylvania Crusher Co. To assist the



For 2500 pound Service—

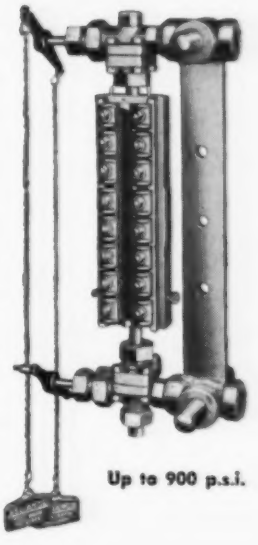
Reliance Super-Duty Gages

Rugged all-welded direct-to-drum assemblies

Various combinations of Reliance Gage Valves, Gage Inserts and Illumination have been supplied to power plants *since 1940* when Code changes called for two water gages on boilers operating over 400 p.s.i. Assemblies for higher pressures feature single, double or triple window inserts welded to flanges for valve connection in "L" end construction. Units for pressures to 900 p.s.i. can be made in tie-bar construction.

Reliance Micasight insert is recommended for higher pressures as by far the safest type known. Windows of selected mica are clamped securely under slotted cover plates — have many times the life of glass. Mica-protected Flat Glass inserts are available for lower pressures, recommended only to 1500 p.s.i. Efficient illumination, an extra, can be supplied for all types of gage assemblies.

Send specifications — pressure, visibility length, etc. — for recommendations and price.



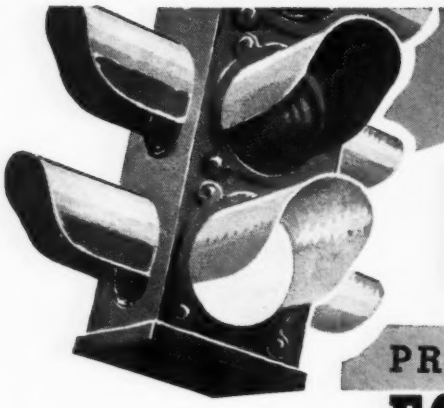
The Reliance Gauge Column Co.

5902 CARNEGIE AVENUE • CLEVELAND 3, OHIO

The name that introduced safety water columns....in 1884

Reliance®

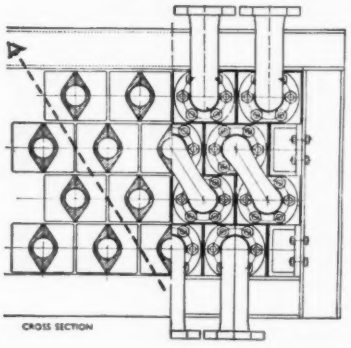
BOILER SAFETY DEVICES



GREEN

PREMIER DIAMOND ECONOMIZERS

The Economizer with the "Diamond" Design



Here are the four major values in the "diamond" shape of the Green Fuel Economizer:

1... Streamline flow of flue gases gives minimum draft loss

2... Finned tubes give maximum heating surface in given space

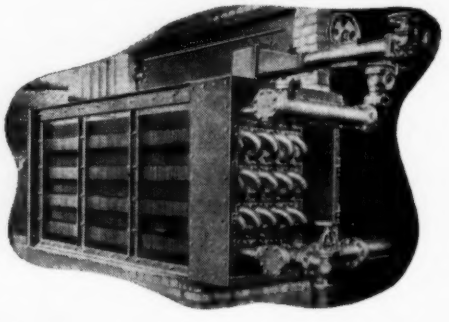
3... Staggered tube arrangement permits easy inspection

4... Minimum soot collecting surface is thoroughly cleaned by Green's "Special" Soot Blowers

Green Premier Diamond Economizers are available in either cast iron tube construction (Type 25) or steel tube construction (Type 12).

Pressure parts are rugged and joint flanges independent of support flanges.

Green Fuel Economizer's reputation of 60 years assures you of satisfactory performance and quality. Send for Bulletin No. 169.



THE GREEN Fuel Economizer COMPANY INC.

BEACON 3, NEW YORK

ECONOMIZERS • FANS • AIR HEATERS • CINDERTRAPS

engineer who may want, on some occasion, to select a crusher, this bulletin explains in a simple nontechnical manner the various crushing methods and where they apply in crushing procedure.

Proportioning Pumps

A 24-page catalog issued by the Hills-McCanna Co. gives full information on their line of mechanical drive "U" type metering and proportioning pumps. Selection data which are included make possible the specification of pumps to handle any of 300 listed substances that are successfully used with these pumps.

Instrument Calibrator

Republic Flow Meters Co. has prepared a four-page bulletin decribing a portable pneumatic instrument calibrator for calibration and testing of low-pressure instruments and controls. These include flow meters, draft gages, differential pressure transmitters, having ranges from 0 to 20 in. of water (pressure, vacuum or compound).

Industrial Heaters

The Thermobloc Division of Prat-Daniel Corp. has announced a new eight-page, two-color catalog which features a full-color cutaway illustration of a Thermobloc direct-fired heating unit. Various models manufactured by the company are illustrated, both photographically and with line drawings. Specifications and dimensions are also listed.

Overhead Cranes

P. &. H.'s complete line of electrical equipment designed for overhead crane service is the informative subject of a 32-page bulletin just released by Harnischfeger Corp. Various types of electrical crane equipment are expertly presented and explained by photographs, charts, drawings and reading material.

Water-Conditioning Data Book

A greatly enlarged edition of the Permutit Data Book has been prepared by The Permutit Co., New York 36, N. Y. This practical data book supersedes an earlier volume produced in 1949; it has been brought up-to-date and completely revised, presenting a compilation of 77 useful tables. The subjects covered include hydraulics, impurities in water, chemical conversions, saturated steam, boiler-feedwater-makeup requirements, chemicals used in water treatment, alkalinity relationships, specific gravities and chemical reactions. This leatherette-bound volume in 5 by $7\frac{1}{4}$-in. size contains 116 pages and is available to practicing engineers, especially those concerned with water conditioning problems.